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SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation
5 Aerial Way, Syosset, New York

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REPORT NO. SME-AB-3
25 July 1958

PANORAMIC CAMERA SYSTEM FOR A SPIN-STABILIZED SATELLITE

PART I
GENERAL DESIGN FACTORS

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Prepared by: D. Hoff for B. Pollack
B. Pollack
Program Chief

Approved by: A. G. Nash
A. G. Nash
Chief Engineer

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PART I

GENERAL DESIGN FACTORS

ABSTRACT

Part I of Fairchild Report SME-AB-3 is introduced by a discussion of why a spin-stabilized satellite reconnaissance system is practical and represents an optimum for high information content of output.

This introduction is followed by a summary of studies made by Fairchild dealing with the general factors affecting the design of a panoramic type camera for a spin-stabilized satellite reconnaissance system.

Panoramic camera principles are reviewed briefly and the parameters of a panoramic camera system are related to the parameters of the spin-stabilized vehicle. The limitations imposed upon the system by the vehicle and the effect of operational requirements upon design are described.

The necessity of sensing and recording vehicle altitude during photography is discussed.

Considerable attention is paid to the optical and the emulsion characteristics necessary to achieve a high acuity photographic system. Particular stress is laid upon the problem of minimizing image motion on the film during exposure as a means of preserving the potential high acuity. A quantitative relationship between image motion and degradation of resolution is presented as extracted from one of the authoritative references consulted during this study.

A theoretical study of the effects of spin axis "wobble" on image blur and on photogrammetry was conducted as a special effort in this part of the program. The study report is presented as Appendix I. Also an experimental study of the special problems arising from recovery of the film package from the sea is presented in report form as Appendix 2.

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INTRODUCTION

After careful study of all the problems related to the satellite reconnaissance program Fairchild Camera and Instrument Corporation has concluded that the spin-stabilized reconnaissance vehicle offers the best advantages from the standpoint of end product information content. This conclusion is in line with a Rand Corporation Report on Spin Stabilized Satellite Reconnaissance and is reached with a knowledge of the General Electric Company's success with re-entry capsules and with a knowledge of the status of Lockheed's missile program. Fairchild's confidence in the success of the program is confirmed by the Rand Corporation report. In fact, Fairchild's study concurs with the basic parameters established in the Rand Report and justifies them from the practical aspect in generating the detailed parameters required for an actual operational system.

Some of the considerations in arriving at this conclusion are as follows:

a) The spin-stablized vehicle permits lower altitude orbits than the vertical stabilized unit. This obviously means more information from the spin-stabilized system since the scale is larger. (For every 10 miles of increase in altitude, the size of ground detail resolved gets poorer by about one additional foot.)

b) Since the spin-stabilized vehicle can operate at lower altitude, this vehicle can carry more payload weight than the higher altitude vertical stabilized unit. Meetings with the Lockheed Missile Systems Division indicated the critical nature of weight and the important weight-altitude relationship.

c) The spin-stabilized approach offers the most efficient utilization of the weight and space allowance for a camera package. Additionally it offers the most convenient arrangement for properly locating the recoverable capsule both from the standpoint of film path and mechanism reliability and of proper orientation for recovery.

Because of the possibility of capitalizing on the spin of the vehicle to rotate the optical axis in space a spin-stabilized vehicle lends itself ideally to panoramic photography. This is a field in which Fairchild has acquired considerable experience.

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The philosophy of this study has been to consider the short time required for an operational mission as the primary objective and to make parameter trade-offs consistent with this time requirement and still provide the data required. The Rand Corporation Report has accomplished much in this direction.

Having made the decision that a panoramic camera in a spin-stabilized vehicle is an efficient satellite reconnaissance system, it is logical to conduct an analysis of the problem to determine the major factors to be considered in the design of the camera. This report attempts to do this quite completely. Part I of SME-AB-3 treats the engineering analysis of parameters starting with the operational requirements and reaching conclusions as to the design criteria for the program.

Since any high acuity photographic system must be based necessarily on the use of a film that will not limit the performance some extra attention seems justified. It appears logical to analyze the problem sufficiently well in a broad sense to be able to make fairly positive recommendations on the film to be used.

Part I of Fairchild Report SME-AB-3 is entitled "General Design Factors". In this portion of the report the factors to be considered are analyzed. This analysis leads logically to the general design of the camera system which is the subject of Part II of the report.

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ANALYSIS OF GENERAL DESIGN FACTORS

A. Application of the Panoramic Principle to Photographic Reconnaissance from a Spin-Stabilized Vehicle

A spin stabilized vehicle lends itself ideally to panoramic photography, a field in wich Fairchild has recently acquired considerable experience. In this application, the camera design problems are reduced to a minimum since the vehicle provides the all important scanning with the lens. The camera need only move the film past the exposure slit in synchronism with the image motion during photography. It would be well, in this introduction, to discuss briefly the panoramic principle to be employed in this study.

Basically, when a camera scans an object by physically rotating it with no shutter in the unit, the images of the object at the focal plane will smear across the format at the velocity V equal to the angular rate of scanning times the lens focal length as a lever arm. Expressed mathematically:

$$V = wF \tag{1}$$

where w = angular scan rate (radians/sec)
F = lens focal length (inches)
V = image velocity across focal plane (inches/sec)

To avoid this smearing it is necessary to move the film at the same velocity V as the image. There is one additional requirement, however, and that is, to avoid excessive exposure, since image and film are synchronized indefinitely, to provide a slit with a width that would produce the required exposure time. This slit width is determined simply by the velocity of the film and the desired exposure time. Again expressed mathematically:

$$W = Vt \tag{2}$$

where W = slit width (inches)
V = film or image velocity (incles/sec)
t = exposure time (seconds)

Equations (1) and (2), then, make up the total fundamental expressions for designing a panoramic camera. The images of the object scanned are "painted" on the film through the narrow slit as the film moves past it. No shutter is required in this type of camera since the slit width determines the exposure time. The ensuing study report will treat actual values for the operational conditions.

B. General System Parameters

1. Operational Requirements of the Specific Vehicle-Reconnaissance System

Fairchild's contacts with the Lockheed Missile Systems Division and the Rand Corporation provided the knowledge of the basic operational requirements for the mission under study. The fundamental requirement is to photograph the target area from an orbiting satellite and recover the film for intelligence purposes. In line with this fundamental requirement the following operational parameters have been established:

a. Operational mission to be successfully accomplished within six to eight months from go-ahead.

b. A passive spin-stabilized reconnaissance pod is to be used for the satellite.

c. A re-entry capsule shall be used containing the exposed film for recovery.

d. The total pod weight including the data capsule and re-entry rocket shall not exceed 300 pounds.

e. The vehicle speed = 25,000 ft/sec = 4 minutes of arc/second oriented as a polar orbit around the earth.

f. The vehicle altitude = 135 statute miles for camera parameter considerations.

g. Vehicle acceleration - 10 g's launch.

h. Vehicle power supply - 28 volts D.C. (Battery Supply)

i. Environmental Conditions

1) Camera Operation

a) Temperature range = +40°F to +120°F
b) Pressurized Pod = 1 atmosphere maximum to 1/3 atmosphere minimum
c) Vehicle movements = due to camera reactions - camera reactions to be kept to an absolute minimum.

2) Recoverable Cassette

a) Operational environments - same as camera
b) Re-entry environments - 4000g's shock for two to three milliseconds.

2. Photographic Design Objectives

a. Provide 36 minutes of active photography covering approximately 300 statute miles of swarth width with approximately ten percent overlap along the line of flight.

b. Resolution requirement - detect an object on the ground of approximately 10 feet.

c. Photography to be taken at all times of the year at latitudes from approximately 45° North Latitude to 75° North Latitude.

d. Provide necessary data to permit location of ground points to a design objective of ±1 mile.

3. Basic Parameters Established for the Photographic System by the Vehicle and the Operational Requirements

Perhaps the single most important limitation in selecting camera parameters for a reconnaissance system is the weight and space limitation established. The Rand Report established or derived most of the following basic parameters. Fairchild's study of these parameters in conjunction with a study of light levels and scale factor considerations have resulted in the selection of a 24 inch lens instead of a 12 inch lens as recommended in the Rand Report. This subject is covered more completely in subsequent sections.

Basic Design Parameters

a. Maximum Camera Weight (including 13 pounds of film) = 60 lbs.

b. Maximum Take-up Cassette Weight = 9 lbs. empty.

c. Lens focal length = 24 inches.

d. Film width = 5 inch film.

e. Transverse angular coverage (derived from ground swath width requirement of 300 statute miles) = approximately 93°.

f. Vehicle Spin Speed = approximately 25.0 rpm. (This value is analyzed more fully in this study report).

g. Vehicle Wobble to be kept to a minimum. (A wobble study is included in the appendix of this report).

A brief discussion of the basic design parameters itemized above is in order at this time. Since all remaining parameters in this study report hinge on the above values, it is important to justify them in order to assure a firm foundation for the subsequent study.

A picture of the weight breakdown is approximately as follows:

Pod Structure	=	22 lbs.
Beacon & Antenna	=	30 lbs.
Telemetering	=	10 lbs.
Battery Support	=	6 lbs.
Batteries	=	29 lbs.
Environmental Control	=	10 lbs.
Capsule & Cassette (with film)	=	109 lbs.
Re-entry Rocket	=	36 lbs.
Camera System	=	47 lbs.
Total Weight	=	299 lbs.

The limitation of film capacity is brought about due to system weight and the size of the re-entry capsule which is fully developed. Hence the largest standard film width that could be considered was 5 inch wide film. The total film capacity was then established in accordance with the ground coverage requirements to be approximately 1500 ft. for a 24" focal length lens. This capacity results in a roll of film of about 9 inches in diameter. Since a cassette had to be provided to enclose this roll of film for recovery, this size and weight was considered maximum for the 16-1/2 inch inside diameter re-entry sphere.

The other basic design parameters spelled out will be covered more thoroughly in the subsequent sections of this preliminary study report.

C. Derivation of Camera Cycling Rate, Film Transport Rate and Slit Width from Basic Parameters

As outlined in Part I Section B., a 24 inch focal length lens and a 5 inch film have been selected. The width of the panoramic photograph is therefore 4-1/2 inches wide and the angular coverage of the lens in the flight direction is 10° 44'. In order to insure a minimum 10% overlap of ground coverage at vertical, the minimum altitude is used in conjunction with the vehicle speed to determine the cycling rate of the camera. The minimum altitude is assumed to be 135 statute miles which is equivalent to 713,000 feet. At this minimum altitude the lens will cover a distance of 133,584 feet or 25.3 statute miles on the ground in the direction of vehicle motion. For 10% overlap a photograph must be taken every time the vehicle covers a distance of 133,584 feet minus 10% or 120,226 feet. For a vehicle forward velocity of 25,000 feet/sec., the time required to travel 120,226 feet is 4.8 sec. In other words the cycling rate of the camera has to be at least 1/4.8 exposures per second.

Since the cycling rate of the panoramic camera is related to the scan velocity and scan velocity in turn is related to the rotational spin rate of the vehicle, not more than one exposure can be taken during one revolution of the vehicle. This relationship would establish 1/4.8 = 0.208 rev/sec as the minimum rotational spin of the vehicle. If a higher spin rate of the vehicle is selected, it has to be a multiple of 0.208 rev/sec and an exposure will be still taken at intervals of 4.8 seconds.

In order to select a vehicle spin rate most favorable for the camera operation, reference is made to the equations (1) and (2).

film velocity: $V = WF$ (in/sec); where: W = angular scan velocity (rad/sec)

exposure time: $t = \frac{W}{V}$ (sec) F = focal length of the lens (in.)

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V = image velocity across focal plane (inches/sec)
W = width of exposure slit (in.)
t = exposure time (secs.)

For the camera under study the camera scan velocity and the vehicle spin rate are equal. Therefore, for a spin rate of .208 rev/sec the scan velocity is: W = .208 x 2 = 1.306 rad/sec.; the film velocity is; V = 1.306 x 24 = 31.34 in/sec; and the width of the exposure slit for an exposure time of t = 1/4000 sec. becomes W = Vt = 31.34/4000 = .00784 inches. Such a narrow exposure slit is obviously not practical, since a variation of the slit by .001 inches would result in an exposure error of 12%. Since it can also be assumed that a spin rate of only 1/5 rev/sec will present stabilization problems, a faster spin rate is preferred.

Faster spin rates will increase the exposure slit width for a given exposure time, reducing the tolerance problem, increase the efficiency of shutter and decrease the danger of "banding". But faster spin rates will also magnify the problem of film synchronization, since the equation V=WF has to be satisfied. The film is driven across the exposure slit by a servo motor. Any error in the film velocity "V" will result in a relative displacement between image and film and create a "blur" reducing the resolution of the photograph. If it is assumed that the camera film drive system will move the film with a velocity within 1% of the required velocity WF, the resulting "blur" will be proportional to the spin rate "W". In other words a higher spin rate will result in more degradation of the photograph due to "blur" if the film drive error is assumed to be a constant percentage of the film speed.

Thus, a compromise between the two conflicting requirements of low spin rate preferred for film synchronization and high spin rate preferred for exposure slit consideration has to be found. This compromise must also consider the important system consideration of spin stabilization of the vehicle.

At present it is felt, that a spin rate in the order of 25 rpm which is in excess of the 18 rpm recommended in the Rand Report, is an excellent compromise. The camera will take a photograph every second revolution. This will result in an actual spin speed of 25 rpm to give exposures every 4.8 sec. with a resulting overlap of 10%.

The film velocity is then:

$$V = WF = \frac{25 \text{ rpm}}{60} \times 2 \quad \times 24 = 62.8 \text{ inches/second.}$$

For an exposure time at 1/1000 sec. a velocity error of 0.5% will produce a blur of $\frac{62.8}{200 \times 1000} = .000314$ inches.

Referring to curve drawing 951L52 such a "blur" will reduce the resolution of the photograph from 100 lines/mm to approximately 95 lines/mm. At faster shutter speeds the "blur" will be proportionately reduced, but "blur" caused by other conditions (as described in other sections of this report) has to be added to one produced by the film velocity synchronization error.

As recommended in the Rand Report the scan angle of the camera has been set at 93°. This angle will produce a transverse ground coverage of approximately 285 statute miles for minimum altitude. The scan time at a spin rate of 25 rpm is .62 seconds. During this time, since a 24-inch focal length lens is used, 39.0 inches of active format length of film is exposed at a rate of 62.8 inches/sec.

D. Derivation of Image Motion Compensation Requirements From Basic Parameters

The forward motion of the vehicle will produce an image motion in the focal plane. The general equation for this image motion is:

$$I.M. = \frac{V}{H} F \text{ (inches)} \quad (3)$$

where V = forward velocity of vehicle (ft/sec)
H = altitude of vehicle (ft)
F = focal length of lens (inches)

In the panoramic camera "H" varies with the scan angle and the equation reads:

$$I.M. = \frac{V}{H} \cdot F \cdot \cos \quad (4)$$

where = scan angle measured from the vertical (degrees).

For a minimum altitude of 713,000 feet, a velocity of 25,000 ft/sec and a scan angle of 0°.

$$I.M. = \frac{25,000}{713,000} \times 24 = 0.84 \text{ inches/sec.}$$

Such an image motion will produce a "blur" of .00084 inches over an exposure time of 1/1000 sec. At a scan angle = 46.5° the blur will decrease to .00059 inches.

E. Discussion of Attitude Sensing and Recording Requirements

Several means of establishing the true vertical have been investigated. It was felt during these investigations that while the establishing of the vertical and the vehicle attitude in the direction of spin was extremely important, the establishing of the vertical in the direction of the forward motion was only of secondary importance. This approach was based on the fact, that an accurate recording of true vertical during the exposure scan is required for any photogrammetric calculation of the scale factor of the photograph, with the zero point of the system coinciding with the nadir point and the Y and y axis in the direction of flight, and X and x perpendicular to it, then the scale factors of a panoramic photograph become:

$$\frac{x}{X} = \frac{x}{H} \cot \frac{x}{F} ; \qquad \frac{dx}{dX} = \frac{F}{H} \cdot \frac{1}{\mathrm{Sec}^2 \frac{x}{F}} \tag{5}$$

$$\frac{y}{Y} = \frac{F}{H} \cos \frac{x}{F} ; \qquad \frac{dy}{dY} = \frac{F}{H} \cos \frac{x}{F} \tag{6}$$

From the above equation it is evident that the establishing of a true "x" is of great importance, while an error in the "y" value will result in only a minor error in establishing ground distances.

The sensing of attitude in the direction transverse to the flight axis will facilitate the triggering of the film transport mechanism, since this triggering has to occur 46.5° from the vertical.

F. Resolution and Exposure Considerations

1. General

The resolution requirements and exposure necessary in a reconnaissance camera are closely allied functions. Invariably, the parameters selected must be a compromise to give the best overall system efficiency rather than being able to choose the optimum condition for each requirement. Since image motion exists due to vehicle motion and scanning operations and compensation for all these undesirable motions is complex and at best only partially compensated for relatively short exposure times are necessary to limit the smear or blurring of the image during exposure.

With given light conditions of aerial photography, a relatively short exposure time demands a large aperture lens and/or high speed film emulsions. Unfortunately, both large aperture lens and high speed film emulsion parameters lead in a direction of reduced resolution capability. Specifically in the case of this program where the delivery time for the hardware prohibits new developments in lenses and film emulsions, it is necessary to select the best known components available to arrive at the best overall results.

2. Exposure Factors

In determining the required exposures for the Panoramic camera, several factors must be taken into consideration. Among the most important are scene brightness and brightness ratio at the camera, spectral distribution of image forming light, film speed, film spectral sensitivity, film quality capability, shutter speed, aperture, film processing, time of day, month and cloud cover.

For convenience, each major factor is considered separately prior to the discussion of the interdependence of these factors.

a, Brightness

Scene brightness on the ground is calculated from standard equations and from experimental data.* Scene brightness includes both direct illumination and sky light in the horizontal plane. Based on the best data available to this organization, assumed average values of 0.1 for atmospheric reflectivity (no cloud cover), 0.9 for atmospheric transmissivity and 0.2 for ground reflectivity were then used to complete the calculation of scene brightness of a ground target from above the atmosphere observed. Drawing 951L39 presents this data plotted as a function of solar altitude.

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* 1) Smithsonian Physical Tables, 9th Revised Edition and
2) Smithsonian Meterological Tables, 6th Revised Edition.

b. Scene Brightness Ratio

Drawing 951L39 indicates only the actual brightness available at the camera. The amount of information available on the film is, however, also a function of the brightness ratio of the image forming light. As we consider decreasing solar altitudes, an increasing percentage of the light reaching the camera is from atmospheric reflection. This adds an increasing uniform illumination to the ground target light thus lowering the apparent target brightness ratio. The decrease in target contrast with increasing percentage of sky light (decreasing solar altitude) is indicated in Drawing 951L40 where target contrast is plotted as a function of solar altitude for (1) the case of a black target against an average ground background of reflectivity 0.2 and for (2) the extreme case of a black target against snow with a reflectivity of 0.9.

c. Spectral Distribution of Image Forming Light

With decreasing solar altitudes, the percentage of total scene illumination contributed by sky light increases as indicated in Drawing 951L41. At very low and decreasing solar altitudes the spectrum of the direct illumination shifts rapidly towards the red while sky light is still predominately in the blue region. These factors allow the choice of several techniques for obtaining photographic information at low solar altitudes. First, use of a minus blue filter will increase scene contrast by eliminating a large portion of sky light reflected by the atmosphere and simultaneously lower the exposing brightness of shadow areas while essentially maintaining the exposing brightness of highlights. However, elimination of sky light will both increase the required exposure and greatly decrease, if not eliminate, shadow detail. In the second case, omitting color filters will allow recording both highlight and shadow detail, but will result in extremely low target brightness ratios at the camera. Finally, infinite number of scene contrasts between these two extremes can be obtained by choice of the degree of blue light filtering.

d. Film Characteristics

1) Spectral Sensitivities

All films that can be favorably considered for use in the Panoramic camera on the basis of speed, quality, and availability have completely adequate spectral sensitivity characteristics.

2) Quality and Speed

At any given time in the state-of-the-art of silver halide sensitization, image quality capability varies as some inverse function of film speed. This fact immediately presents a balance between film quality and speed that must be made in the choice of a suitable emulsion since it is necessary to obtain both high quality images and the longest possible operational day. At one extreme, ultra-high speed emulsions have relatively low inherent contrasts, a characteristic incompatible with the necessity for obtaining high quantities of information from medium contrast targets. The relatively low resolution and acutance, and high granularity of these materials contribute significant degradation of information quality to the lens-film system (for the quality capabilities of the chosen lenses). At the other extreme, choice of ultra-high quality emulsions results in a lens-film quality that is lens limited, and, the inherent high contrast of these low speed - high quality materials will increase the resultant image contrast of medium contrast targets. However, as the illumination level decreases a point is reached where exposure times must be increased to obtain proper film exposure and image quality will decrease rapidly as a result of increasing image motion, resulting in a shortened operational day.

(It is assumed that exposures will be chosen to give emulsion densities yielding the highest overall quality possible for the given brightness range and emulsion.)

3. Computation of System Quality as a Function of Length of Operational Day

a) Scene Brightness at Various Locations and Times

For a given day, time and geographical location, film exposing brightness is computed using equation (7) to determine solar altitude and Drawing 951L39 to determine scene brightness at this solar Altitude.

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$$\sin\alpha = \sin\lambda \cdot \sin\delta + \cos\lambda \cdot \cos\delta \cdot \cos 15t \qquad (7)$$

where: α is the solar altitude in degrees.
λ is the latitude (North).
t is the time in hours from noon. (local)
δ is the declination where $\sin\delta = \sin T \sin 23.5°$.
T is in days with March 21 = 0.

Drawing 951L42 presents scene brightness above the atmosphere of ground targets as a function of time of day for three latitudes at the two extremes of declination (±23.5°).

b) <u>Brightness required for Given Exposure Time and Lens-Film Combination</u>

Calculation of scene brightness required for a given exposure time was made utilizing equation (8).

$$B = \frac{K.C.T^2}{t.S_W} \qquad (8)$$

where: B = Scene Brightness (foot-lamberts)
K = Constant defining working density on film negative (0.5)
C = Filter factor (transmission reduction) (2.0)
t = Effective exposure time (sec.)
S_W = Emulsion sensitivity rating (Weston speed)
T = T Stop number (4.3)

In all calculations, film speed criteria are chosen so as to place the various scene brightnesses on the film in a manner that will allow maximum utilization of inherent film resolution (which is a function of exposure and film processing) and that will result in a minimum of 1 stop exposure latitude for the given scene brightness ratio.

These data are plotted in Drawing 951L44.

c) Resolution Degradation Resulting from Image Motion

Experimental work in connection with varying amounts of relative motion (motion between film and image) have been performed (Romer[1] and Gregory[2]) showing the degradation in resolution with motion.

These experiments were carried out with actual lens-film-camera combinations and with precisely controlled motion being introduced to observe the degradation. These data are plotted in Drawing 951L52.

Using synchronization errors of 0.22 inches per second and forward motion compensation error of 0.09 inches per second, the vector sum image motion for various exposure times is plotted in Drawing 951L53. *

Using Drawings 951L52 and 951L53, resolution degradation resulting from image motion for a given emulsion, used with the proposed system, can be readily determined.

d) Consolidation of Data for Determination of System Resolution as a Function of Length of Photographic Day

Drawings 951L54, 951L55 and 951L56 present system resolution as a function of length of photographic day for three different latitudes during two days, one representing the maximum scene brightness the other representing the minimum scene brightness available during the year.

Using the criteria chosen for obtaining the calculations presented in Drawing 951L44, major decreases in system resolution will not appear until image motion becomes appreciable. Resolution degradation, appearing as target contrast decreases, have been compensated for by contrast control during film processing to the greatest extent possible for the given emulsion. After maximum useable contrast has been attained resolution decreases rapidly with decreasing target contrast.

* 1) "Suppression of Image Movement in Air Photography" - W. Romer, D.Techn. Sc., Poland, F. Inst. P., F.R.P.S.Royal Aircraft Establishment, Farnsborough, Hants, England.
2) "Interim Reports on the Effect of Image Movement on the Definition of Air Photographs" - J.M. Gregory, Kodak Research Labs; Harrow, England, AT1165074, F52-2-1947 Reel C-6723.

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G. Recommendations As to Film Emulsion

1. General Discussion

a) Choice of "Best" Emulsion

Choice of "best" emulsion for this system is, in the ideal case, a simple matter of determining the emulsion that results in the highest quality image for the longest operational day (time during which photography of the given quality is possible). However, in the actual case, many factors which are not completely reducible to quantitative relationships are important in overall system analysis. Additionally, no completely satisfactory technique exists for quantitatively measuring system quality (by "quality" it is meant the magnitude of usable information density that can be obtained from the final product). Although quality is also a function of such film and/or lens characteristics as acutance and granularity, comparisons are made solely on the basis of resolution. Considering the accuracy of data and assumptions required for the succeeding calculations, resolution is probably an adequate criterion of system quality.

b) Super XX vs. Aerecon Plus X

From Drawings 951L54, 951L55 and 951L56 it can be seen that for any specified time of year, latitude, and length of photographic day Aerecon Plus X is superior to Super XX in terms of lens-film-processing resolution.

In addition to this advantage in resolution, several distinctive characteristics of Aerecon Plus X not considered in the foregoing analysis are extremely advantageous when used in the proposed system. Aerecon Plus X has an acutance capability that is superior to Super XX and maintains this capability even at realtively high densities. Aerecon Plus X also lends itself to automatic contrast control at constant exposure speed or to speed control at constant contrast during processing far better than any other emulsion now commercially available.

c) Aerecon Plus X vs. SO-1213

Neglecting considerations of the length of photographic day, use of SO-1213 results in a far greater maximum lens-film-processing resolution than Aerecon Plus X. Along with superior resolution, SO-1213 exhibits acutance and contrast characteristics significantly higher than Aerecon Plus X. The only limitations of SO-1213 are its relatively low sensitivity (speed) and that although the inherently high contrast of SO-1213 <u>would allow</u> the use of forced developing techniques to increase exposure speed, this would still not result in an exposure speed comparable to that which could be obtained with Aerecon Plus X without destroying its higher image quality capability. Finally, SO-1213 does not have the desirable characteristics of Aerecon Plus X that result in the wide range of the proeessing control discussed in the previous section.

Since the total misssion length is somewhat limited and the possibility exists of using different films at different times of the year, it is recommended that SO-1213 be used when the length of photographic day using SO-1213 is sufficient to satisfy operational requirements. This will result in the maximum image quality. However, for several winter months at latitudes greater than 65°, SO-1213 does not have sufficient sensitivity to obtain images at exposure times where SO-1213 still has a resolution superior to Aerecon Plus X. During these periods, it is recommended that Aerecon Plus X be used (See Drawings 951L57 and 951L58 for plots of SO-1213 resolution as functions of time of year and latitude).

d) <u>Specific Recommendations</u>

1) Aerecon Plus X is superior to Super XX in every respect. It is therefore recommended that Super XX not be used in this system.

2) It is recommended that SO-1213 be used during those times of the year when its use results in a photographic day of sufficient length to satisfy operational requirements during the entire mission (this will be for the major portion of the solar year).

3) At all other times it is recommended that Aerecon Plus X be used.

H. Special Problems

During the course of this investigation it has become necessary to conduct studies of two subjects which arehighly specialized, but yet closely related to the basic study. In fact the outcome of these studies may be very important in deciding upon the approach to design of the whole system and certain subsystems within it. In the one case it seemed desirable to investigate the limitations imposed upon the photographic system by instability in the satellite vehicle caused by deviation of the spin axis from the axis of least moment of inertia. This "wobble" can result in degradation of resolution through image motion blur. It can also interfere with accurate target location. Accordingly a study was conducted and the results reported under the title of Effect of Non-Coincidence of the Spin Axis and the (Minimum) Principal Axis of Inertia on Blur and Photogrammetry. This report forms Appendix 1 of Part 1.

In the second problem it was necessary to resort to experimentation. This probelm was to determine the effects of salt water and dye solution on exposed photographic film. The importance of this matter to the satellite reconnaissance system lies in the plan of recovery of data which depends upon landing the recoverable film package in the sea. The results of the experimentation are reported in Appendix 2 entitled, Effects on Photographic Film Resulting From Immersion in Salt Water and Salt Water Plus Yellow Dye Marker.

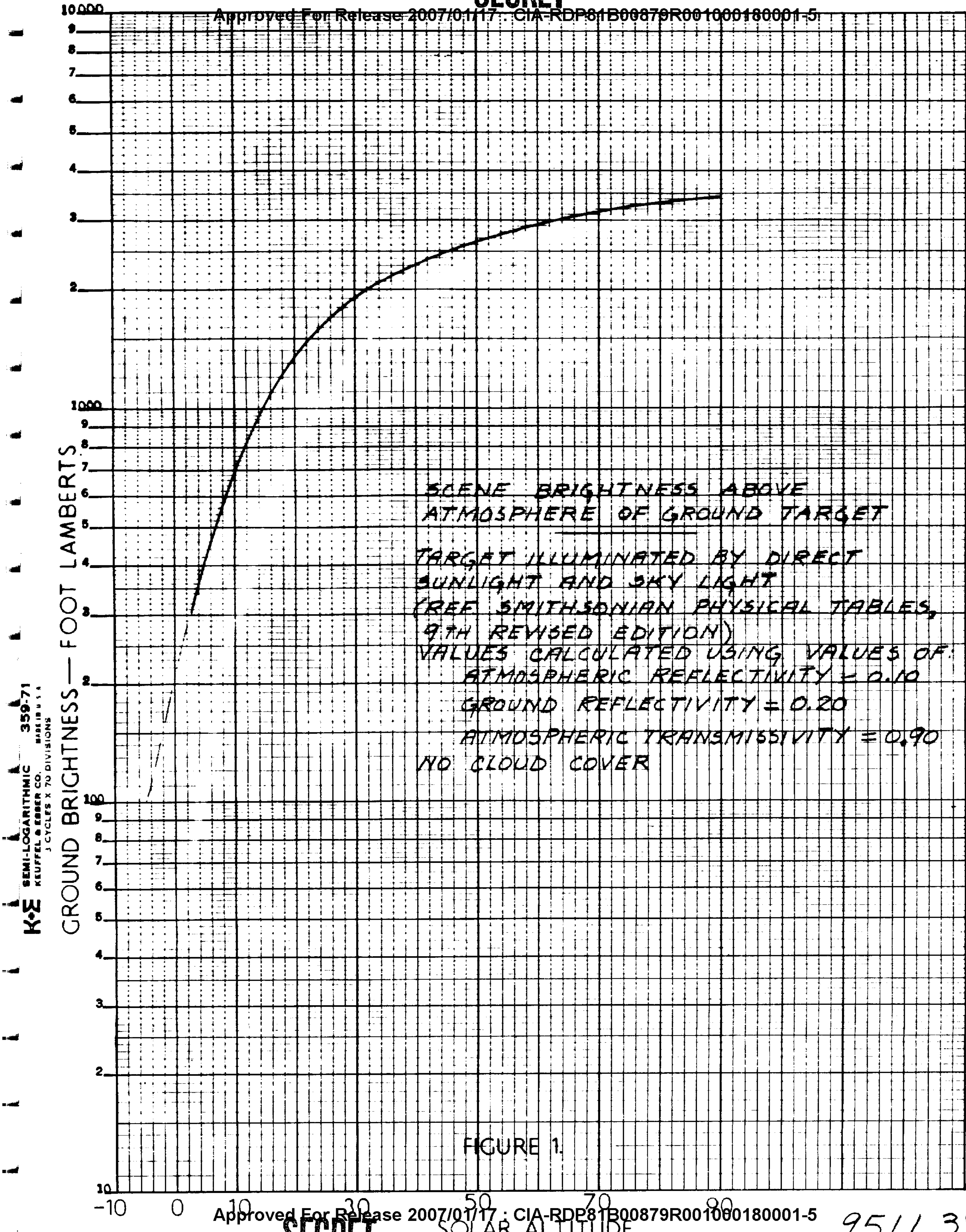


FIGURE 1.

951L39

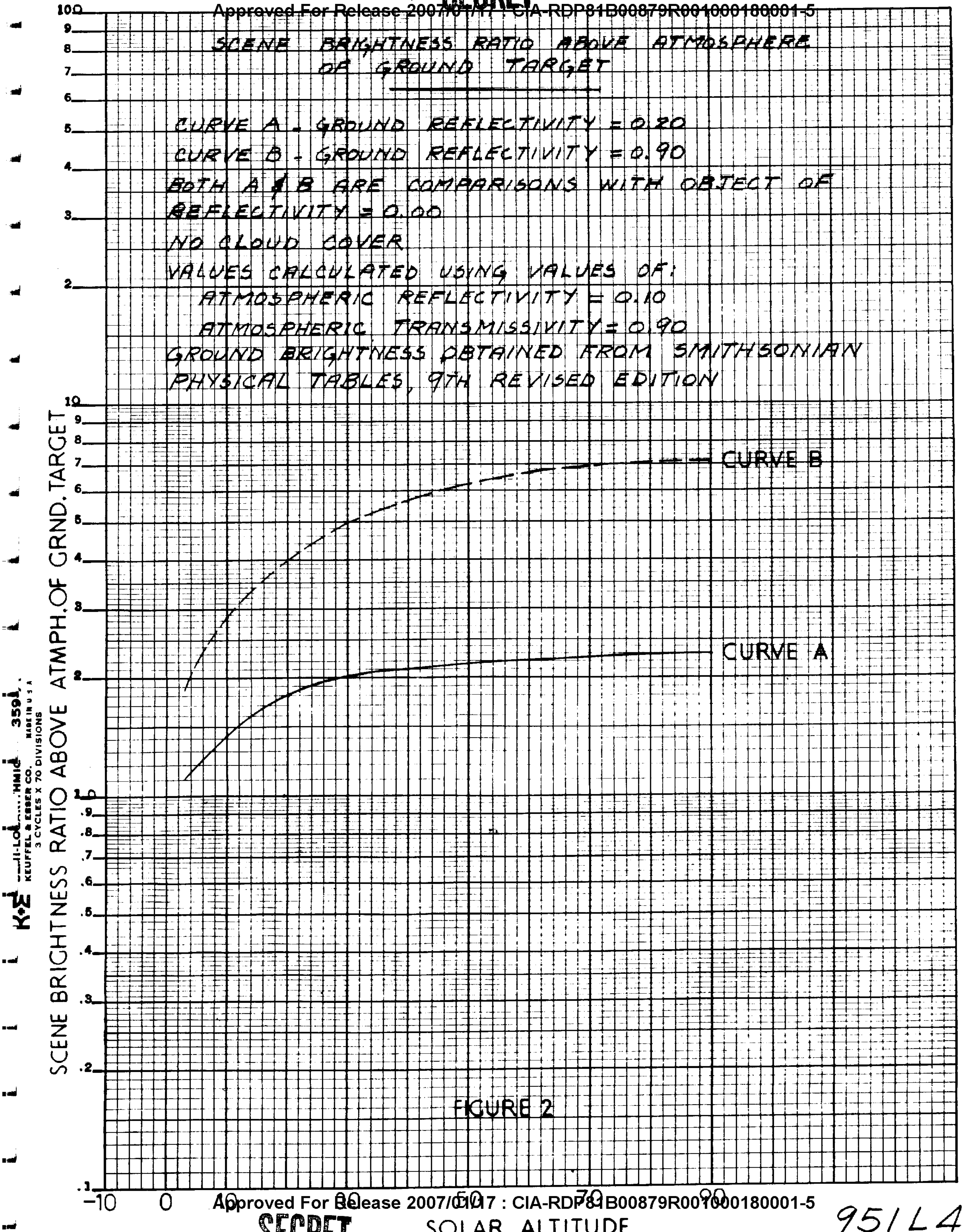
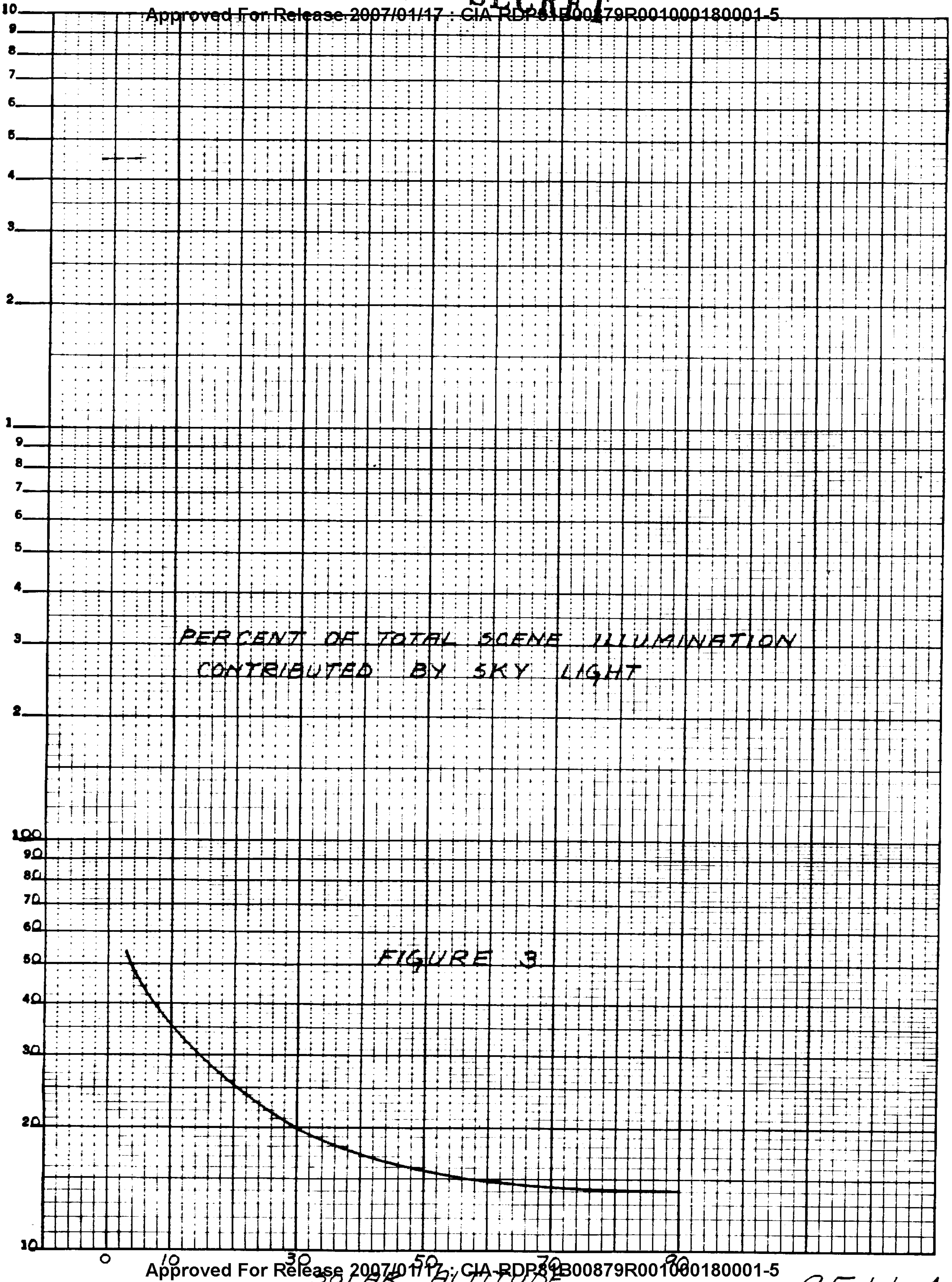


FIGURE 2

951L40


PERCENT OF TOTAL SCENE ILLUMINATION
CONTRIBUTED BY SKY LIGHT
FIGURE 3
100
90
80
70
60
50
40
30
20
10
0
10
30
50
70
90
SOLAR ALTITUDE

951L41

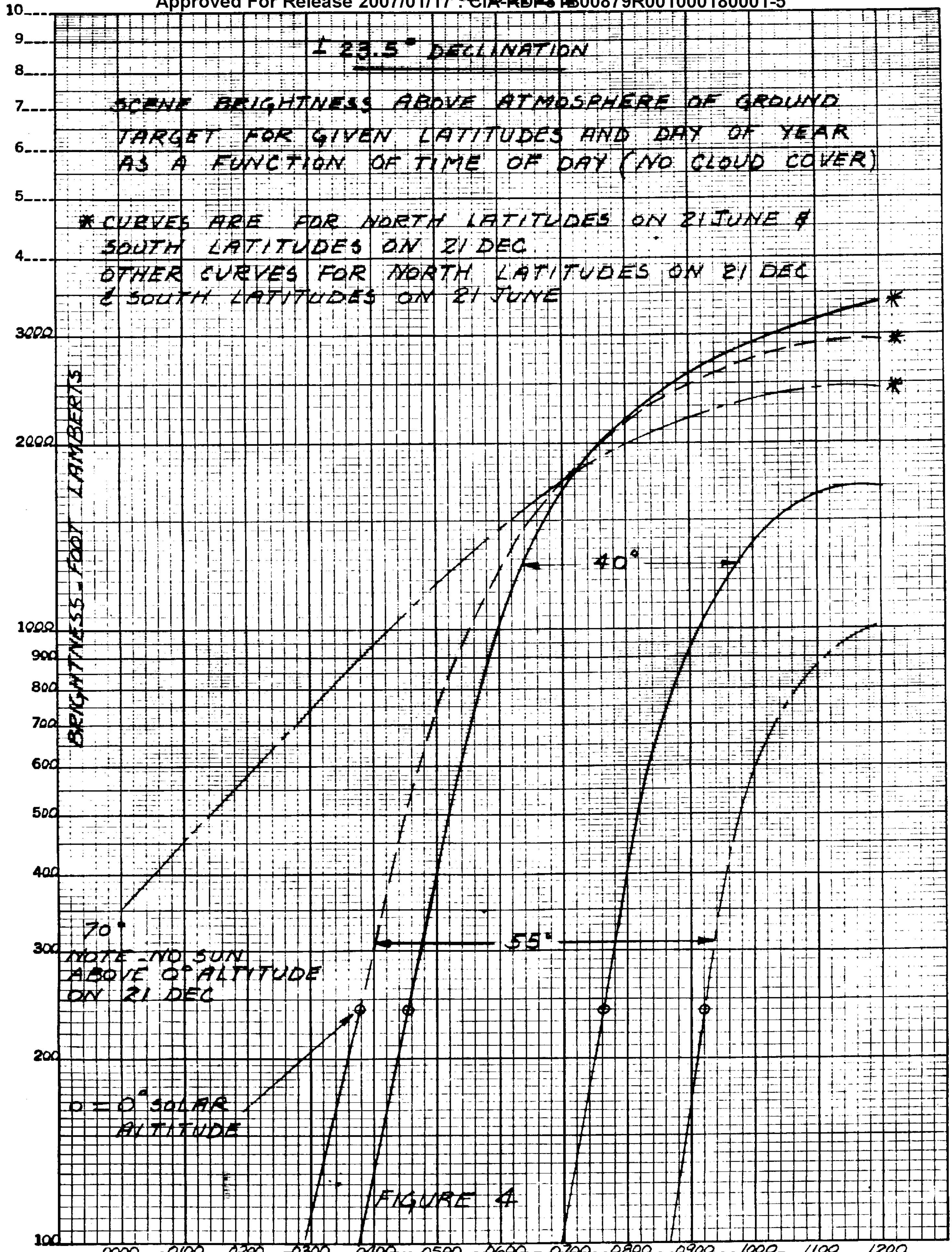


FIGURE 4

SUN TIME

951L42

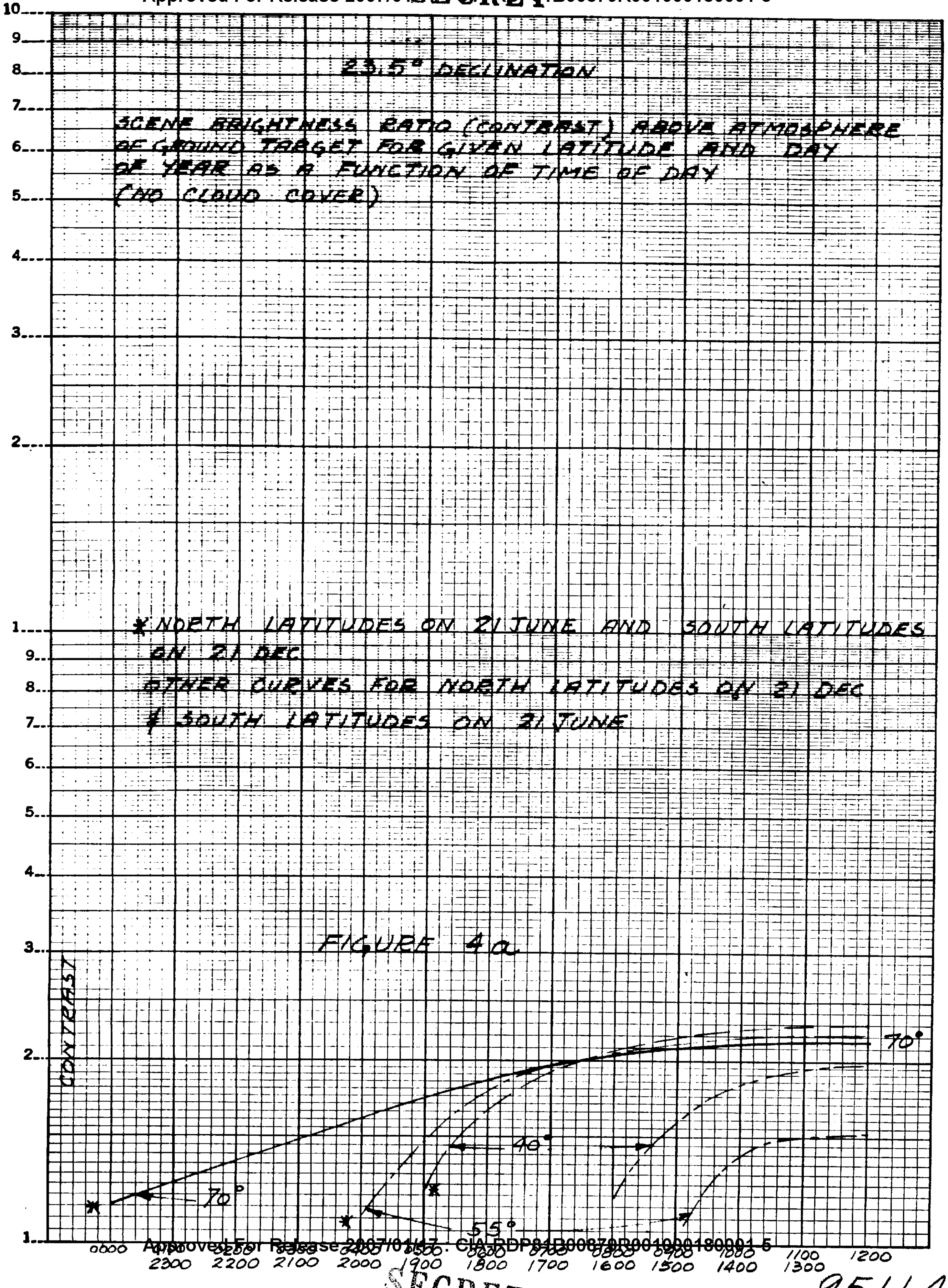


FIGURE 4a

95/443

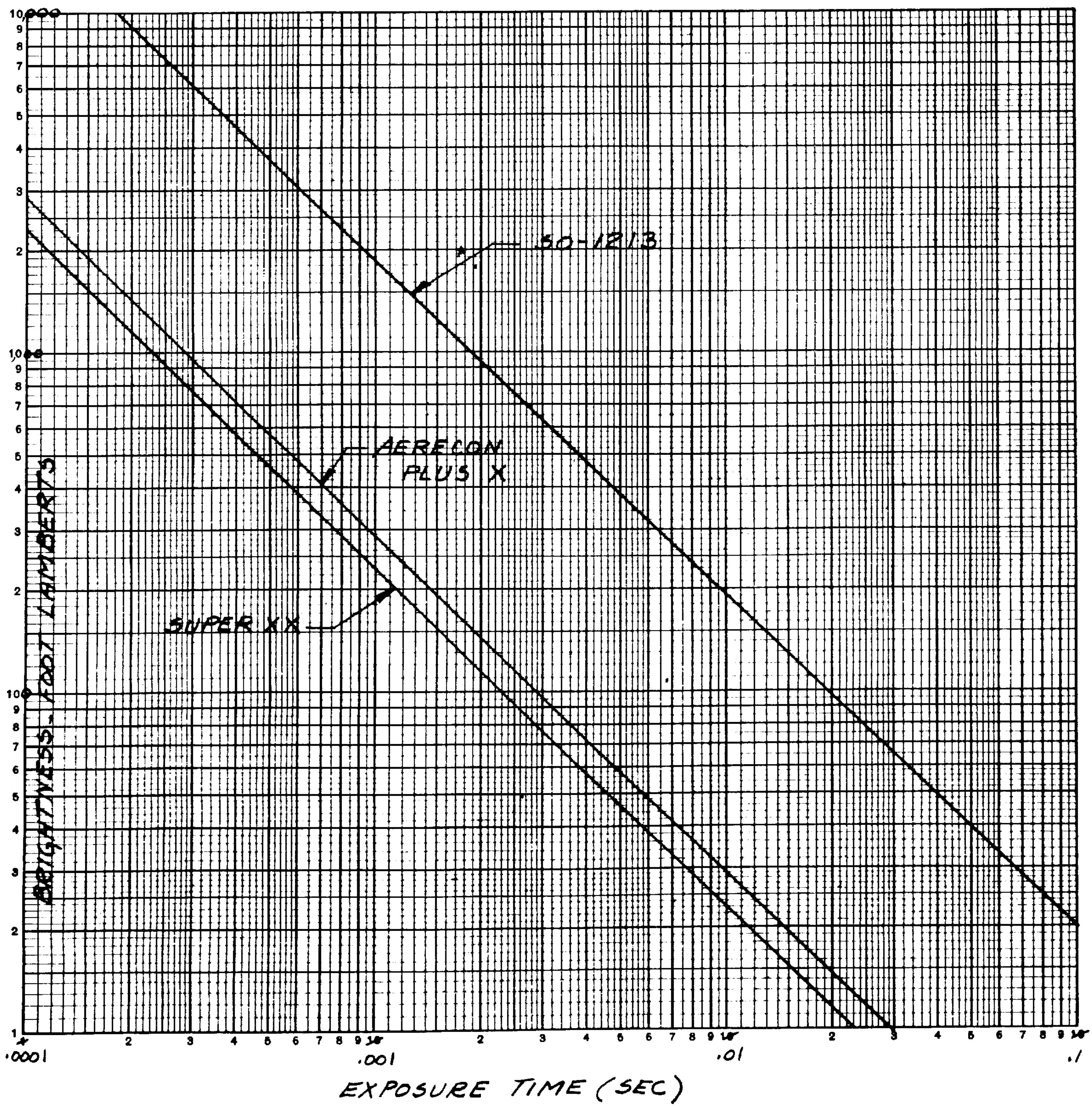


FIGURE 5

951L44

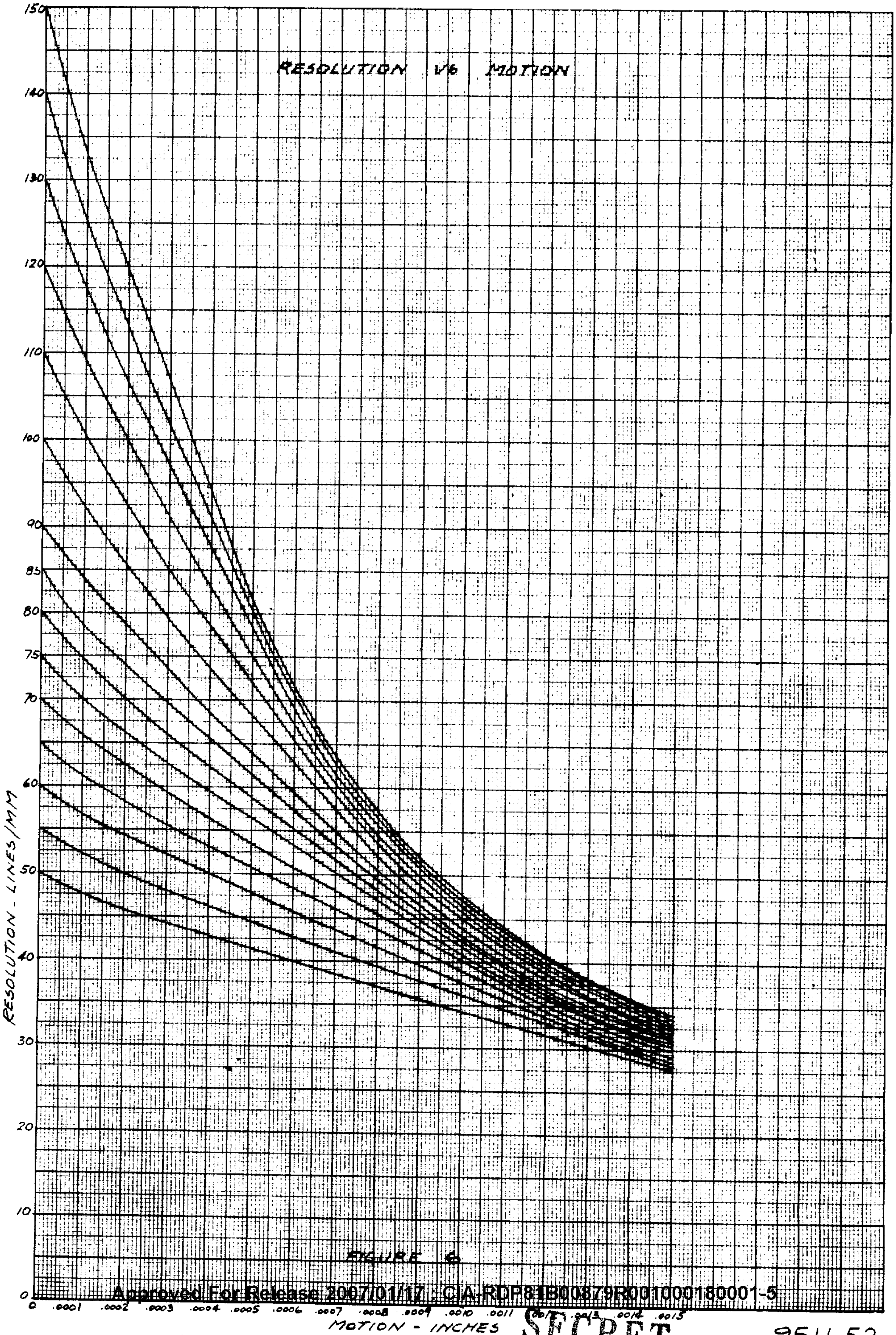


FIGURE 6

951L52

ASSUMING SYNC ERROR = 0.31 IN/SEC
FMC ERROR = 0.0129 IN/SEC.
(24" LENS)

IMAGE MOTION VS EXPOSURE TIME

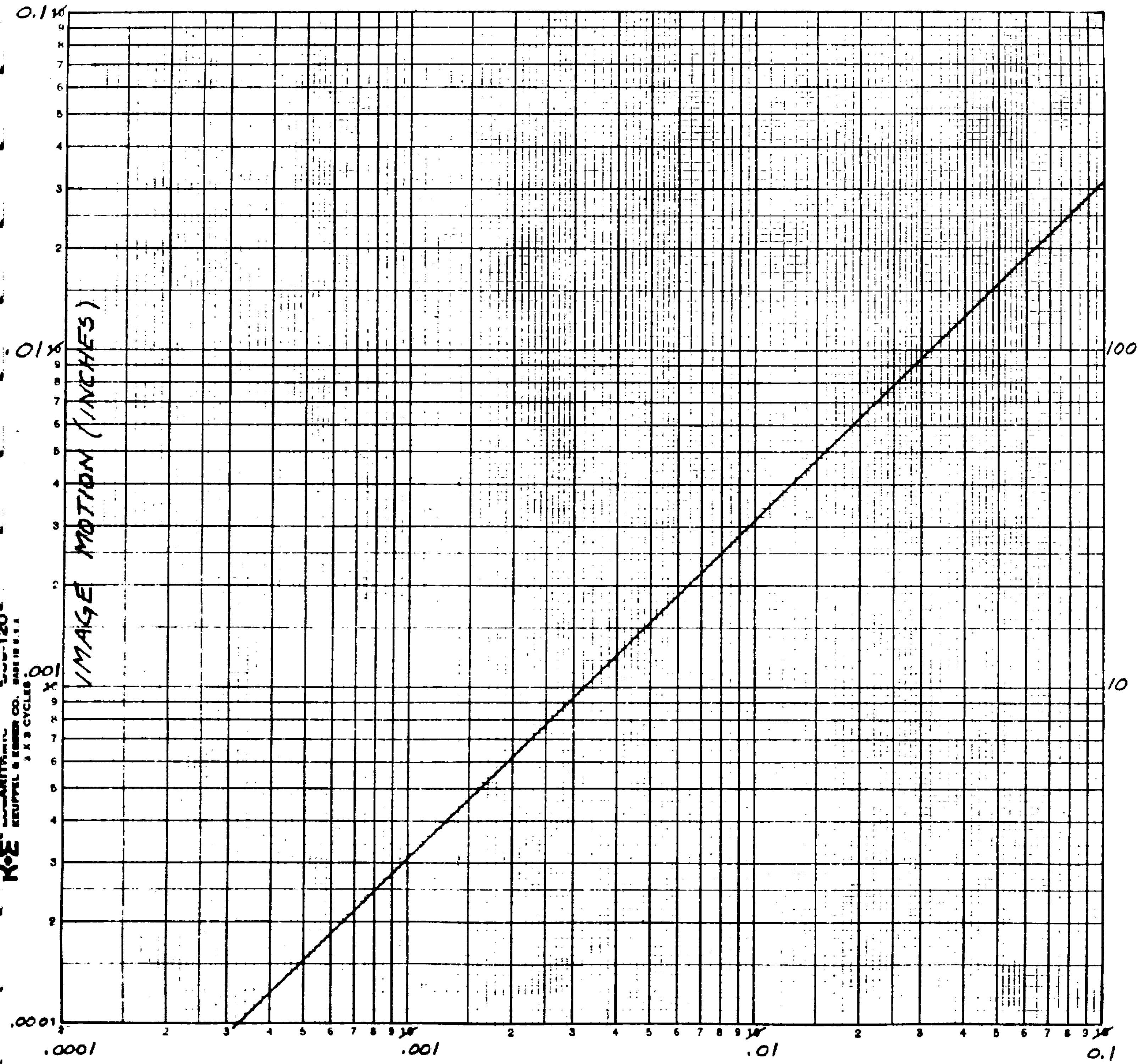


FIGURE 7

95L53

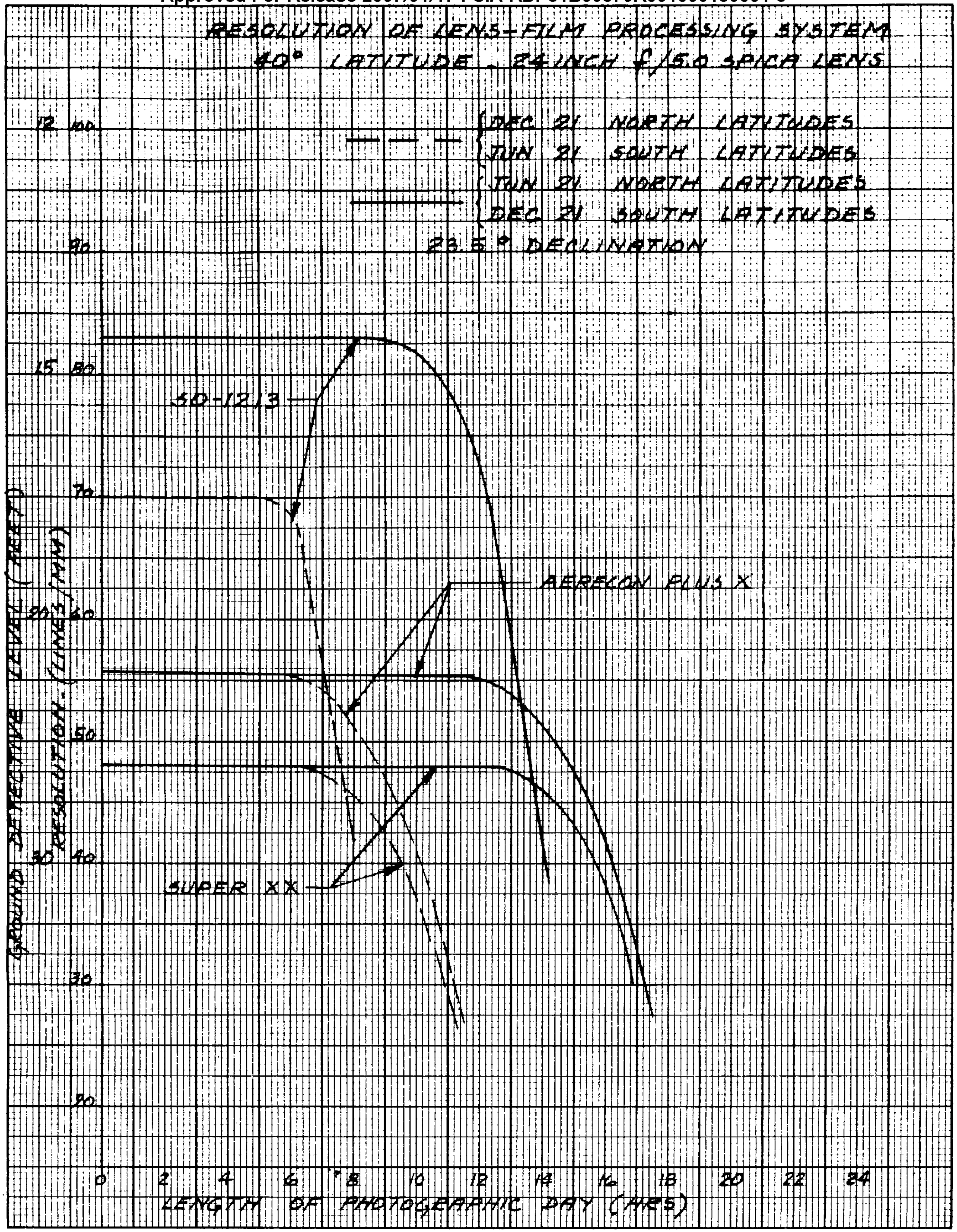


FIGURE 8.

951L54

SECRET

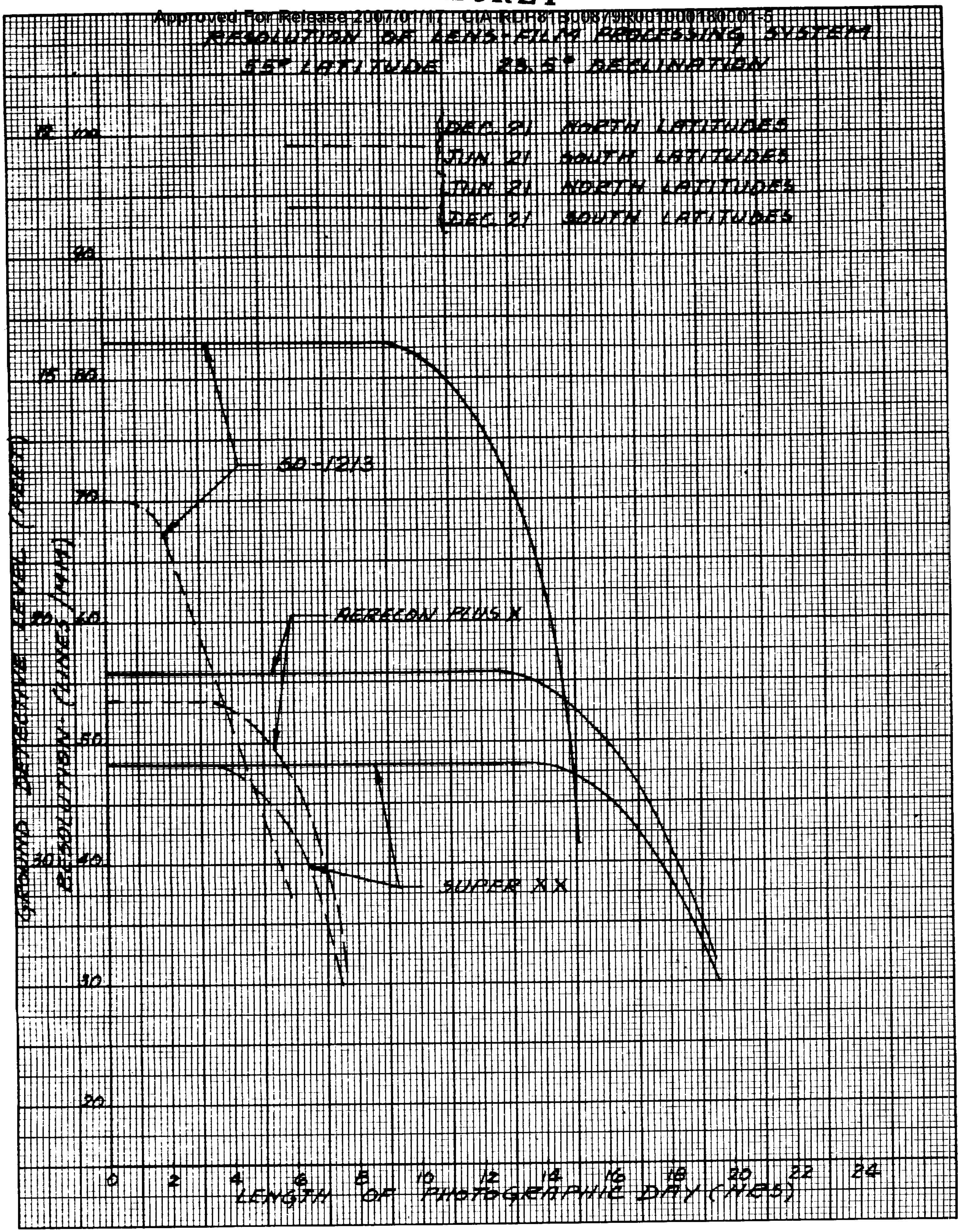


FIGURE 9

SECRET

951L55

SECRET

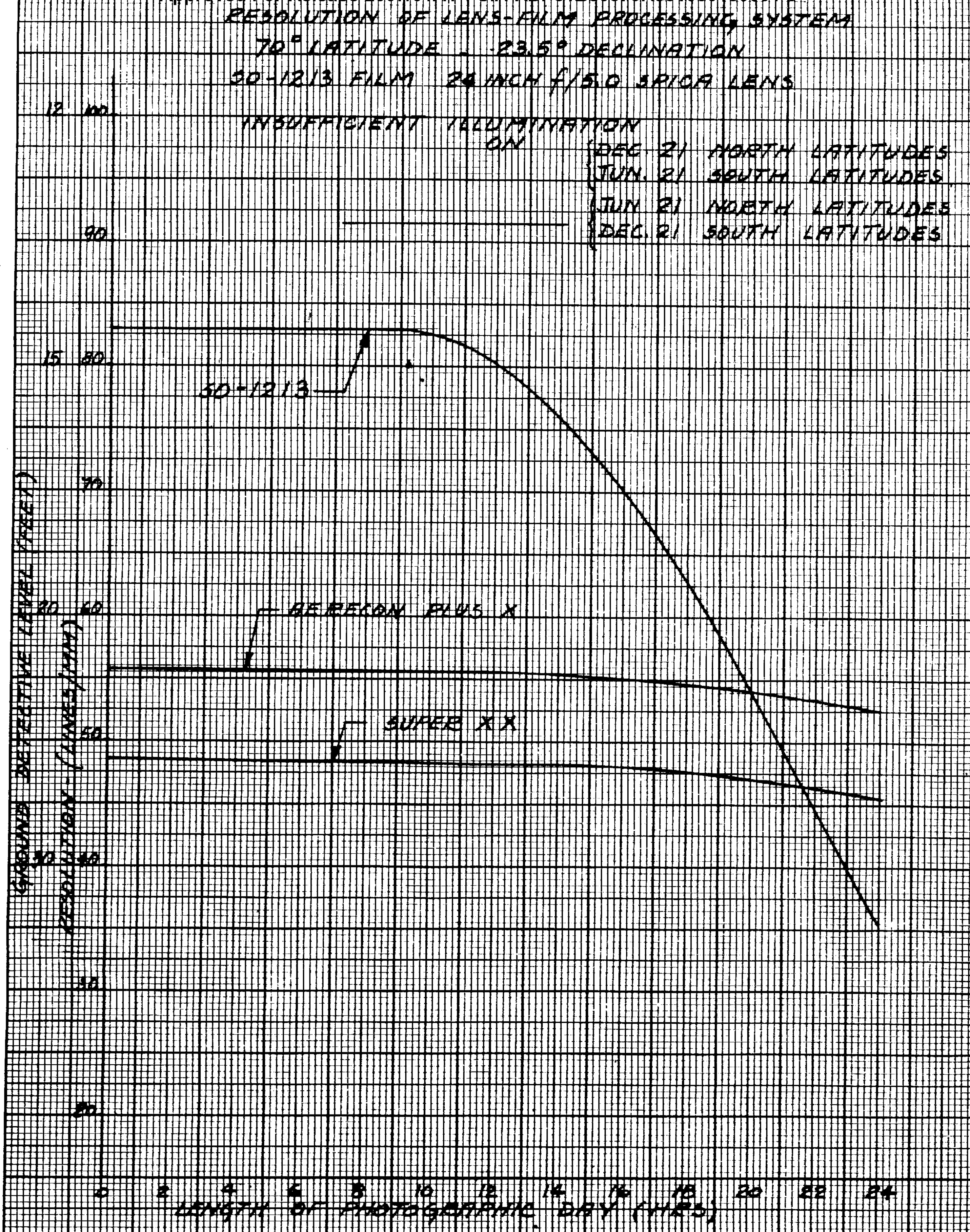


FIGURE 10

SECRET

951L56

SECRET

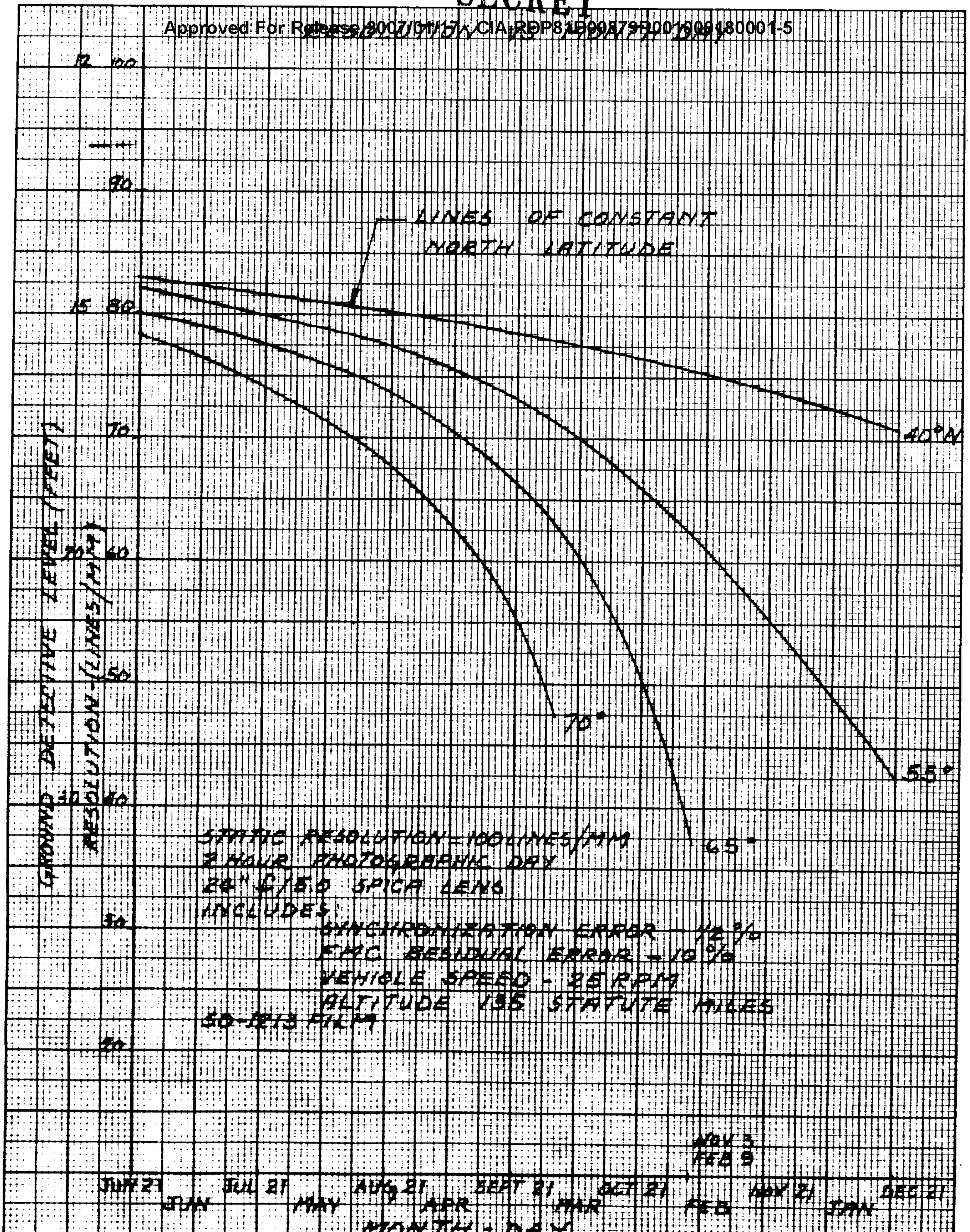


FIGURE 11

951L57

SECRET

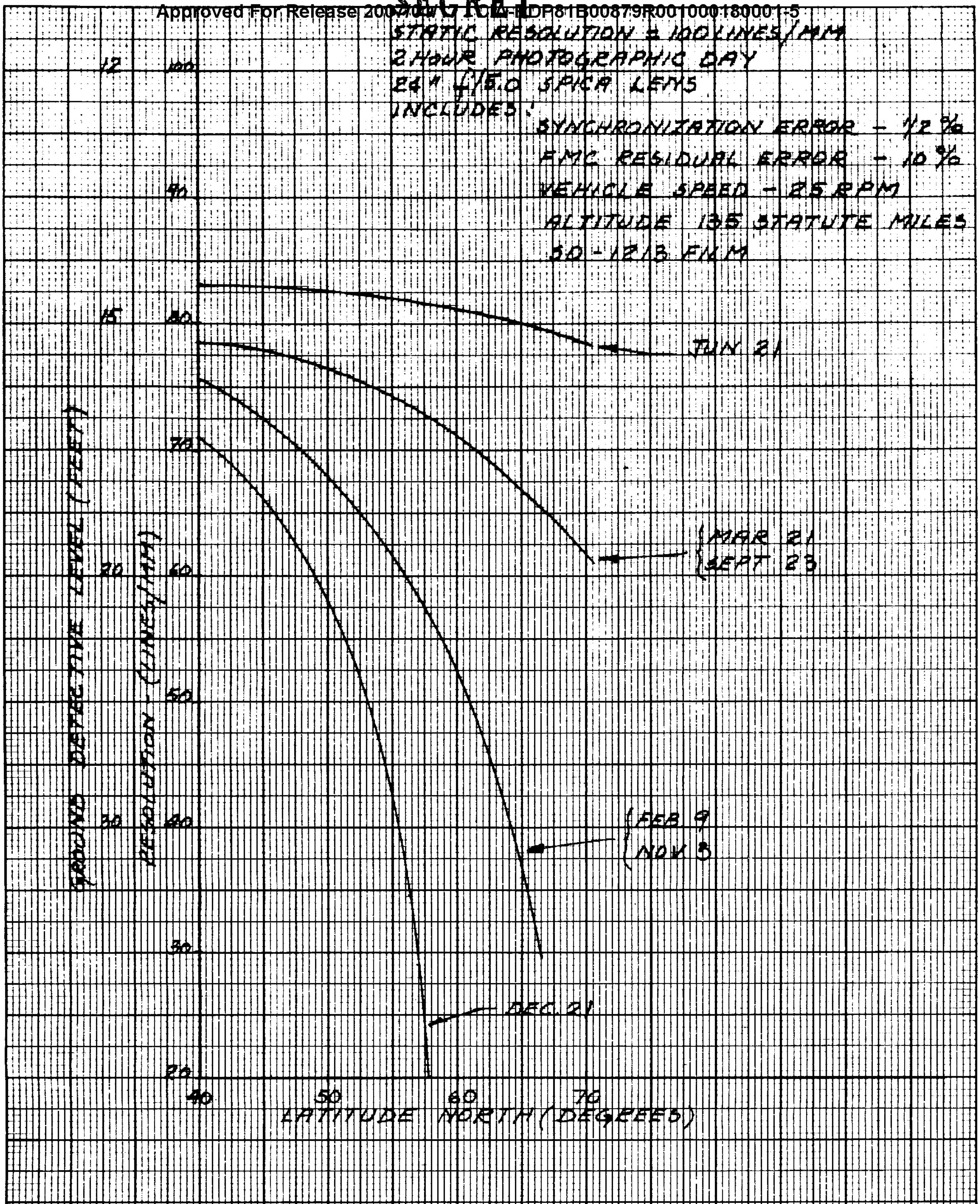
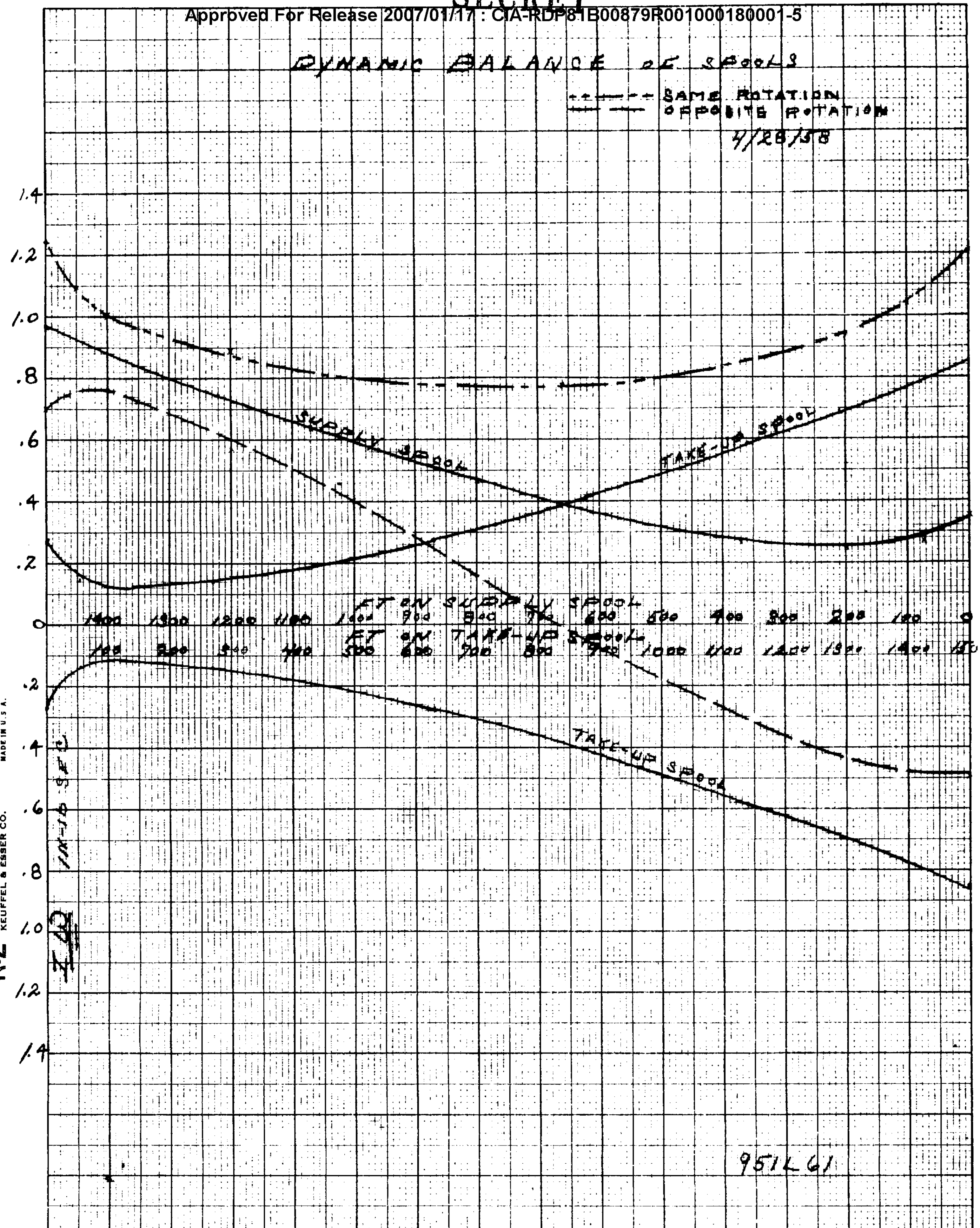


FIGURE 12

951L58


DYNAMIC BALANCE OF SPOOLS
SAME ROTATION
OPPOSITE ROTATION
4/28/58
SUPPLY SPOOL
TAKE-UP SPOOL
FT ON SUPPLY SPOOL
FT ON TAKE-UP SPOOL
1.4
1.2
1.0
.8
.6
.4
.2
0
1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
TAKE-UP SPOOL
IN-LB SEC
I ω
951L61

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

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25 July 1958

APPENDIX I

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation
5 Aerial Way, Syosset, New York

Report No. SME-AW-1
25 July 1958

EFFECT OF NON-COINCIDENCE OF THE SPIN AXIS AND THE (MINIMUM) PRINCIPAL AXIS OF INERTIA ON BLUR AND PHOTOGRAMMETRY

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

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EFFECT OF NON-COINCIDENCE OF THE SPIN AXIS AND THE (MINIMUM) PRINCIPAL AXIS OF INERTIA ON BLUR AND PHOTOGRAMMETRY

I. INTRODUCTION

In order that the relative image-film motion may be determined, it is desirable to establish a coordinate system which is fixed in the rotating vehicle. Thus, in Drawing 951L30, the symmetry axis (z) is the desired spin axis. The optical axis is perpendicular to this and will be considered either the x or the y axis (both fixed in the vehicle). It is expected that the film motion during exposure will be such as to only compensate for a uniform spin "r_o" about the z axis. Thus the film speed will be "$r_o f$" relative to the camera, "f" being the lens focal length.

The spin axis, upon release, may not coincide with the axis of least moment of inertia "z" and a precessional motion will take place with the result that variable angular velocity components exist about the x, y, z axes. These will cause relative motion of the image with respect to the film. If the velocity has a magnitude (s) and the exposure time is τ the blur is given by equation (1)

$$s = \mathring{s}\,\tau \qquad (1)$$

II. COMPONENTS OF THE IMAGE MOTION

To describe the image motion in the plane of the film, a plane system of coordinates (u, v) will be utilized (Drawing 951L31). In terms of this system the linear velocity of the image motion can be written as follows:

$$\mathring{s} = \sqrt{\mathring{u}^2 + \mathring{v}^2} \qquad (2)$$

Denoting the angular velocities around x, y and z axes by p, q, and r correspondingly, the relative linear velocities of the image with respect to the film can be written as follows (denoting the focal distance by f):

a) For rotation about x axis

$$\dot{v} = fp \qquad (3)$$

b) For rotation about z axis

$$\dot{u}_1 = f\,(r-r_o) = fr_1 \qquad (4)$$

c) For rotation about y axis

$$\dot{u}_2 = vq \qquad (5)$$

Since the slit is oriented along v-axis and is sufficiently narrow the component u_2 can be considered as parallel to the u axis and its direction depends on the sign of the v coordinate. Adding equations (4) and (5) we obtain for $\dot{u}$

$$\dot{u} = \dot{u}_1 + \dot{u}_2 = vq_1 + fr_1 \qquad (6)$$

and equation (2) can be written as

$$s = \sqrt{f^2\, p^2 + (vq + fr_1)2} \qquad (7)$$

III. DETERMINATION OF ANGULAR VELOCITIES

Ascribing the moments of inertia around x, y and z axes as A, B and C correspondingly and using the condition $A > B > C$ Eulers equations of motion for a body subject to no external torque can be written in the form

$$\dot{p} = \frac{B-C}{A}\,qr$$

$$\dot{q} = \frac{C-A}{B}\,rp \qquad (8)$$

$$\dot{r} = \frac{A-B}{C}\,pq$$

The solutions of these equations can be written in the elliptic functions as follows:

$$p = p_o \, cn \lambda t$$
$$q = h \, sn \lambda t \qquad (9)$$
$$r = r_o \, dn \, t = r_o \sqrt{1-k^2 \, sn^2 \lambda t}$$

The equations (8) solved in terms of (9) give

$$h^2 = \frac{A(A-C)}{B(B-C)} \left(p_o^2 \right) \qquad (10)$$

$$\lambda^2 = \frac{(A-C)(B-C)}{AB} \left(r_o^2 \right) \qquad (11)$$

$$k^2 = \frac{A}{C} \frac{(A-B)}{(B-C)} \left(\frac{p_o^2}{r_o^2} \right) \qquad (12)$$

Initial values p_o and r_o can be determined from consideration of the motion at the instant when t = 0 (Drawing 951L32), as

$$p_o = w \sin\beta \; , \; r_o = w \cos\beta$$

where β is the angle between z-axis and the direction of the resultant angular velocity (direction of the spin-axis) at time t = 0. The computations for the range of β from 0° to 5°, using the values A = 3.3C, B = 3.0C and w = 18.2 rpm - $\frac{2\pi}{60}$ x 18.2 rad/sec = 1.905 rad/sec. are presented in the Table below:

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TABLE 1

β	p_o	p_o^2	r_o	r_o^2	h	h^2	k^2	λ
0°	0	0	1.905	3.64	0	0		
1°	.0333	.0011	1.905	3.64	.0374	.00140	.00015	1.301
2°	.0663	.0044	1.904	3.63	.0748	.00559	.0006	1.299
3°	.0994	.0099	1.902	3.62	.112	.0126	.0013	1.297
4°	.133	.0177	1.900	3.61	.150	.0225	.0025	1.295
5°	.166	.0276	1.898	3.60	.187	.0351	.0038	1.293

The properties of the elliptic functions are such that for $k^2 \ll 1$, which is the case, they can be approximated by trigonometric functions, and the equations (9) can be rewritten as follows:

$$p = p_o \cos \lambda t \tag{13}$$

$$q = h \sin \lambda t \tag{14}$$

$$r = r_o \sqrt{1 - k^2 \sin^2 \lambda t} \tag{15}$$

Evaluation of $k^2 \sin^2 \lambda_2 t$ shows that in the considered range of β it never exceeds .002 or $k^2 \sin^2 \lambda t < .002$ which justifies the approximation of (15) by

$$r = r_o \left[1 - (1/2)\, k^2 \sin^2 \lambda t\right] \tag{16}$$

the variable component of (16), which will contribute to the blur (Drawing 951L33) may be written from (16), as follows:

$$r_1 = r - r_o = -\frac{1}{2} r_o k^2 \sin^2 \lambda t$$

and finally all angular velocities will be expressed by:

$$
\begin{aligned}
p &= p_o \cos \lambda t \\
q &= h \sin \lambda t \\
r_1 &= -\frac{1}{2} r_o k^2 \sin^2 \lambda t
\end{aligned}
\tag{17}
$$

IV. BLUR DETERMINATION

Combining (1), (7), and (17) the general equation for the blur can be written, as follows:

$$s = \tau \sqrt{f^2 p_o^2 \cos^2 \lambda t + v^2 h^2 \sin^2 \lambda t - 1/2\, vfhr_o k^2 \sin^3 \lambda t + 1/4\, f^2 r_o^2 k^4 \sin^4 \lambda t}$$

The last term under the radical can be neglected giving equation (18)

$$s = \tau \sqrt{f^2 p_o^2 \cos^2 \lambda t + v^2 h^2 \sin^2 \lambda t - \frac{1}{2} vfhr_o k^2 \sin^3 \lambda t}$$

For the case $\beta = 5°$ ($f = 12$ inches, $v = 2.25$ inches) the values of the coefficients are:

$$f^2 p_o^2 = 4.03$$

$$v^2 h^2 = .18 \quad (4.5\%)$$

$$1/2\, vfhr_o k^2 = 0.18 \quad (.5\%)$$

From these values we conclude that the extreme blur is determined essentially by the first term under the radical of eq. (18), so that we have as an excellent approximation the equation:

$$s\ max = \tau f p_o \tag{19}$$

The values of s max are computed and presented in the Table below for values of β from 1 to 5 degrees.

β degrees	1	2	3	4	5
Blur $S_{max.}$ (inches)	1×10^{-4}	2×10^{-4}	3×10^{-4}	4×10^{-4}	5×10^{-4}

V. THE CASE B>A>C

The moments of inertia were specified as $A = B° \pm 10\%$, B and $C = \frac{A}{3}$. For the case considered above it has been assumed $A = B + 10\%$. The case of $A = B - 10\%$, B is essentially equivalent to the optical axis being directed along the x axis. The components of the image motion (Drawing 951L34) will be

$$\dot{u} = u_1 + vp + r_1 f$$

$$\dot{v} = qf$$

and the formula for blur will be

$$S = \tau \sqrt{v^2 p_o^2 \cos^2 \lambda t + f^2 h^2 \sin^2 \lambda t - vfp_o r_o k^2 \cos \lambda t + \frac{}{+ 1/4\, f^2 v_o^2 k^4 \sin^4 \lambda t}}$$

The values of each term are (for $\beta = 5°$, $f = 12$ inches, $v = \pm 2.25$ inches)

$$v^2 p_o^2 = .142$$

$$f^2 h^2 = 5.04$$

$$vfp_o r_o k^2 = .323$$

$$1/4\, f^2 r_o^2 k^4 = .0002$$

and the extreme value of the blur will be given very closely by $S_{max} = \tau fh$

β degrees	1	2	3	4	5
S_{max} (inches)	1.1×10^{-4}	2.2×10^{-4}	3.3×10^{-4}	4.4×10^{-4}	5.5×10^{-4}

so that the blur is larger by 10% than for the case where the lens axis coincides with the major principal axis.

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VI. THE ANGLE BETWEEN THE SPIN AXIS AND THE MOMENTUM VECTOR

The angle between the spin axis and the momentum vector at time $t = 0$ is denoted by α in Drawing 951L32. Then the relationship between α and β may be established as follows:

$$\tan\beta = \frac{p}{r}; \quad \tan(\alpha+\beta) = \frac{Ap}{Cr} = \frac{A}{C}\tan\beta$$

$$\text{or } \frac{\tan\alpha + \tan\beta}{1 - \tan\alpha\tan\beta} = \frac{A}{C}\tan\beta$$

$$\text{and } \tan\alpha = \frac{\frac{A-C}{C}\tan\beta}{1+\frac{A}{C}\tan^2\beta}$$

but $\frac{A}{C}\tan^2\beta \ll 1$, so that $\tan\alpha = \frac{A-C}{C}\tan\beta$ and for $A = 3.3C$, $\frac{A-C}{C} = 2.3$ and $\tan\beta = \frac{\tan\alpha}{2.3}$. Drawing 951L35 presents "β" as a function of "α".

VII. PHOTOGRAMMETRIC CONSIDERATIONS

The transformation equations relating the coordinates (u, v) of the negative to their projection on the horizontal ground plane (assuming the spin axis to be horizontal) are (Drawing 951L36)

$$U = h\tan\gamma \qquad (21)$$

$$V = \frac{h}{f} \times \frac{v}{\cos\gamma} \qquad (20)$$

where $\gamma = \frac{u}{f}$ in radians.

Ten degree increments of γ with f = 1 foot, $h = 713 \times 10^3$ feet and v = 2.25 inches gives the following dimensions for the outline of this projection.

γ	U (in thousand feet)	V
0°	0	135
10°	126	137
20°	260	144
30°	412	156
40°	598	176
46-1/2°	752	185

which is shown on Drawing 951L37,

where L - overall length = 2 U max = 1500×10^3 feet

W - maximum width = 2 V max - 370×10^3 feet

The overall exposure time for a single picture is $T = \frac{93°}{360°}$ Tc, where TC - period of the camera rotation

$$Tc = \frac{2\pi}{r_o} = \frac{6.28}{1.9} = 3.3 \text{ sec.}$$

so that T = .26 Tc = .26 x 3.3 sec. During this time, displacement of the optical axis will occur with respect to the ground surface because of the vehicular ground speed v_g and because of the precessional motion of the vehicle. Displacement due to the ground speed v_g during exposure will be along the V axis and can be computed as follows:

$$\triangle V = v_g \quad T = 25 \times 10^3 \times .85 = 21 \times 10^3 \text{ feet}$$

and can be accounted for.

Evaluation of the displacement due to the precessional motion is equivalent to the problem of blur determination and the formula (19), with modifications, can be utilized.

An upper limit to the displacement can be determined from

$$S_{max} = p_o \; TD \qquad (23)$$

where **D** - distance from the nodal point of the lens to the point on the ground.

Measured along the optical axis it is given by:

$$D = \frac{H}{\cos \gamma} \qquad (24)$$

and for $\gamma = 46\text{-}1/2°$ $\quad D = 713 \times 10^3 \times 1.379 = 983 \times 10^3$ feet.

T = overall exposure time,

p_o = amplitude of angular velocity around x axis of the vehicle (See Table 1).

The period of the precession is very nearly

$$T_p = \frac{2\pi}{\lambda} \qquad (25)$$

From (11) $\lambda^2 = .465 \; r_o^2$ or $\lambda = 1.3$ and $T_p = 4.83$ sec. During one quarter of this period p may change from 0 to its maximum value; but the exposure time is shorter than $1/4 \; T_p$. Thus equation (23) is pessimistic. Assuming that the angle between the momentum vector and the spin axis (α) does not exceed 3°, the angle between spin axis and Z-axis of the vehicle (β) will not exceed 1°20' and from the Table 1, p_o will not exceed .045.

$$S_{max} = .045 \times .85 \times 983 \times 10^3 = 37 \times 10^3 \text{ feet.}$$

Relative to the origin of coordinates, the error is half of this value.

$$S_{max} = 18 \times 10^3 \text{ feet.}$$

This is the displacement at the edge of the negative ($\gamma = 46\text{-}1/2°$), where the width of the projected negative is $W = 2V \max = 370 \times 10^3$ feet so that S_{max} is about 5% of W. For the case where the spin axis is not parallel to the horizontal plane, which is equivalent to the case of the optical axis deviating from the vertical by the angle "t" (tilt angle) this displacement in the plane of the scanning optical axis will be larger by a factor of sec (t), which (for $t = 15°$) is $\sec 15° = 1.035$.

GENERAL REFERENCES ON RIGID BODY MOTIONS

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2. L.M. Milne - Thomson, Jacobian Elliptic Function Tables, Dover Publications, N.Y.

3. R.F. Deimel - Mechanics of the Gyroscope - The Dynamics of Rotation, Dover Publications, N.Y.

4. A.G. Webster - The Dynamics of Particles and of Rigid, Elastic and Fluid Bodies, Hafner Publishing Co., N.Y.

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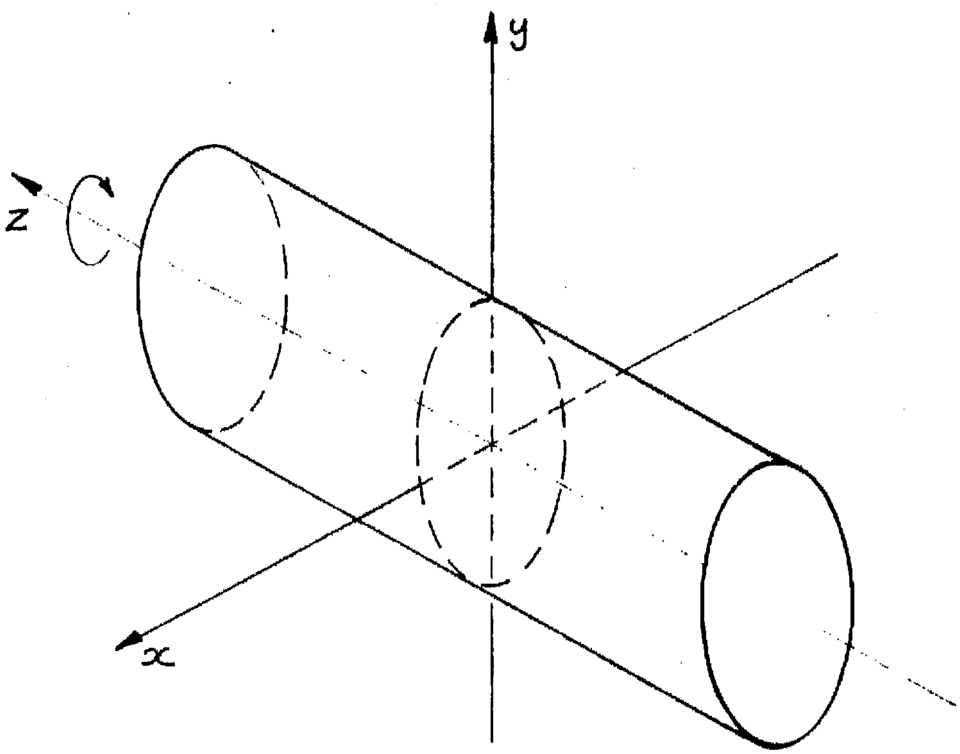

FIG. 1

951L30

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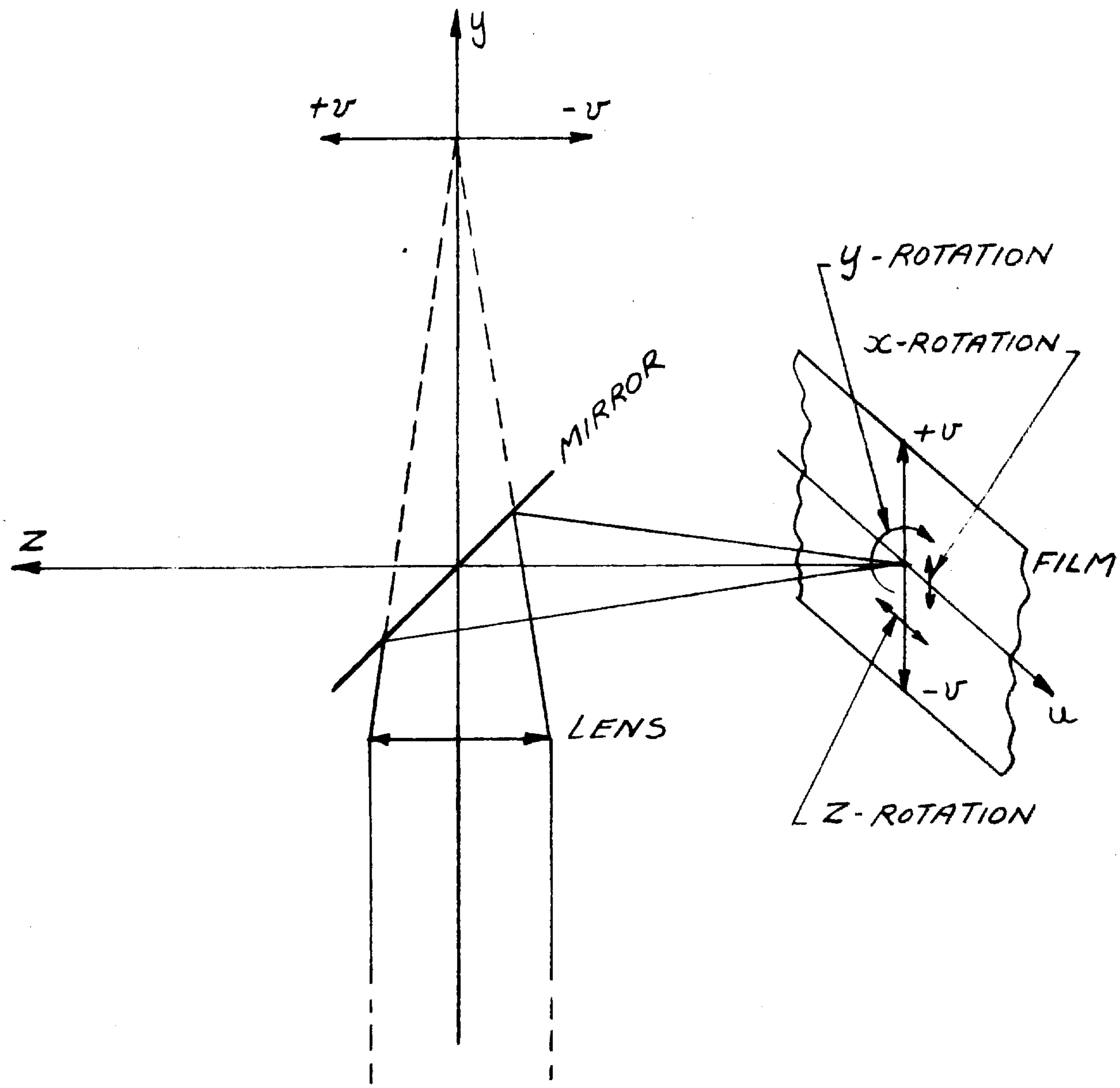

FIG. 2

951L31

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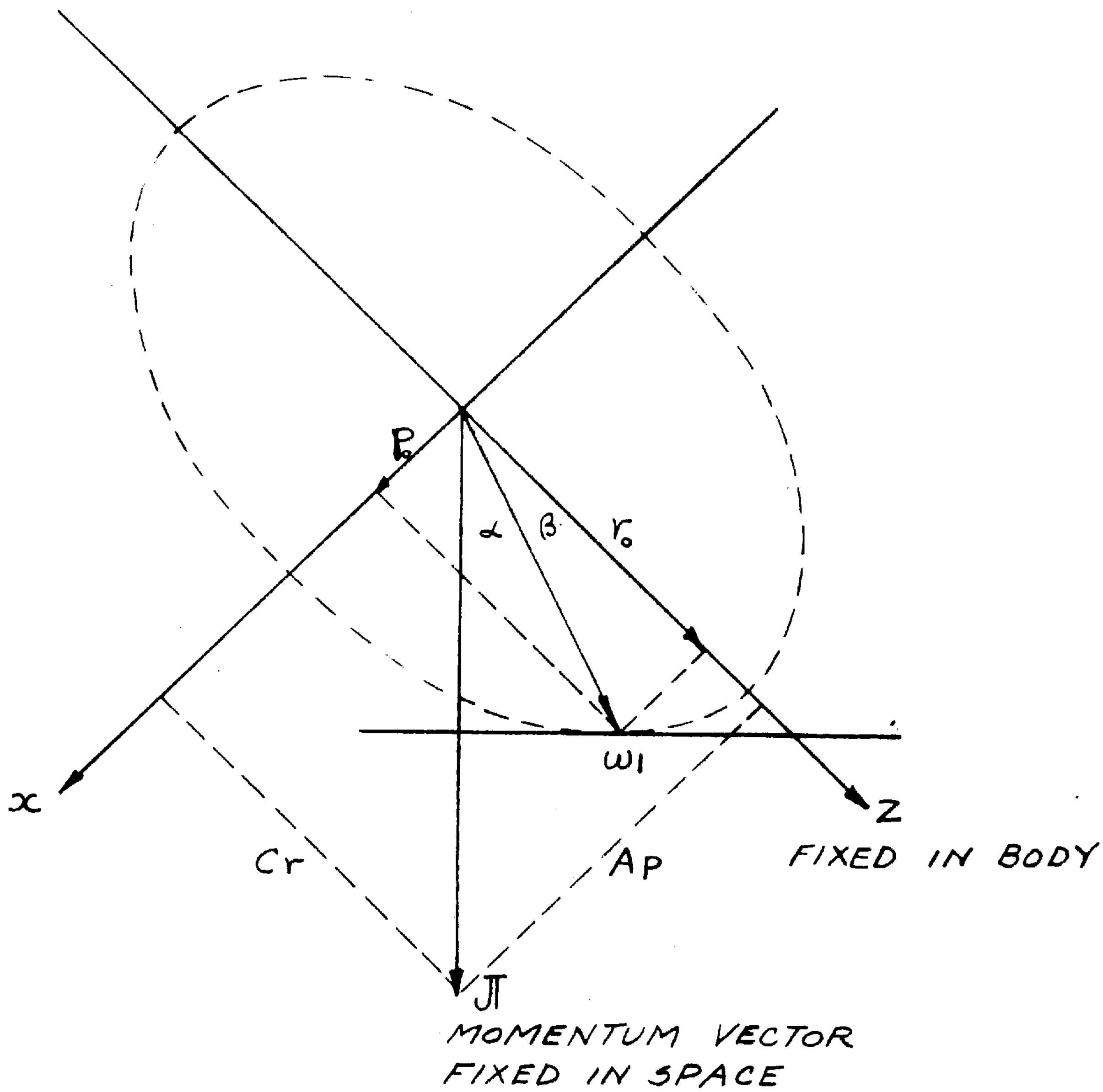

ANGULAR RELATIONSHIPS AT TIME $t=0$

FIG. 3

951 L32

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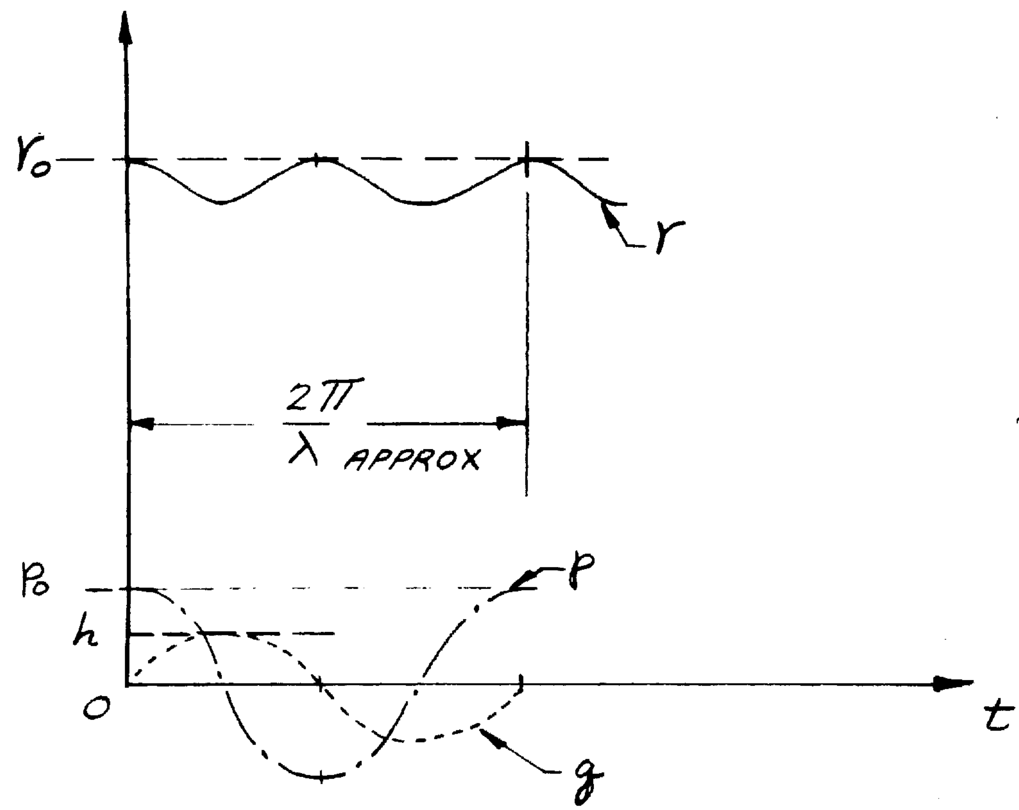

FIG. 4

951 L 33

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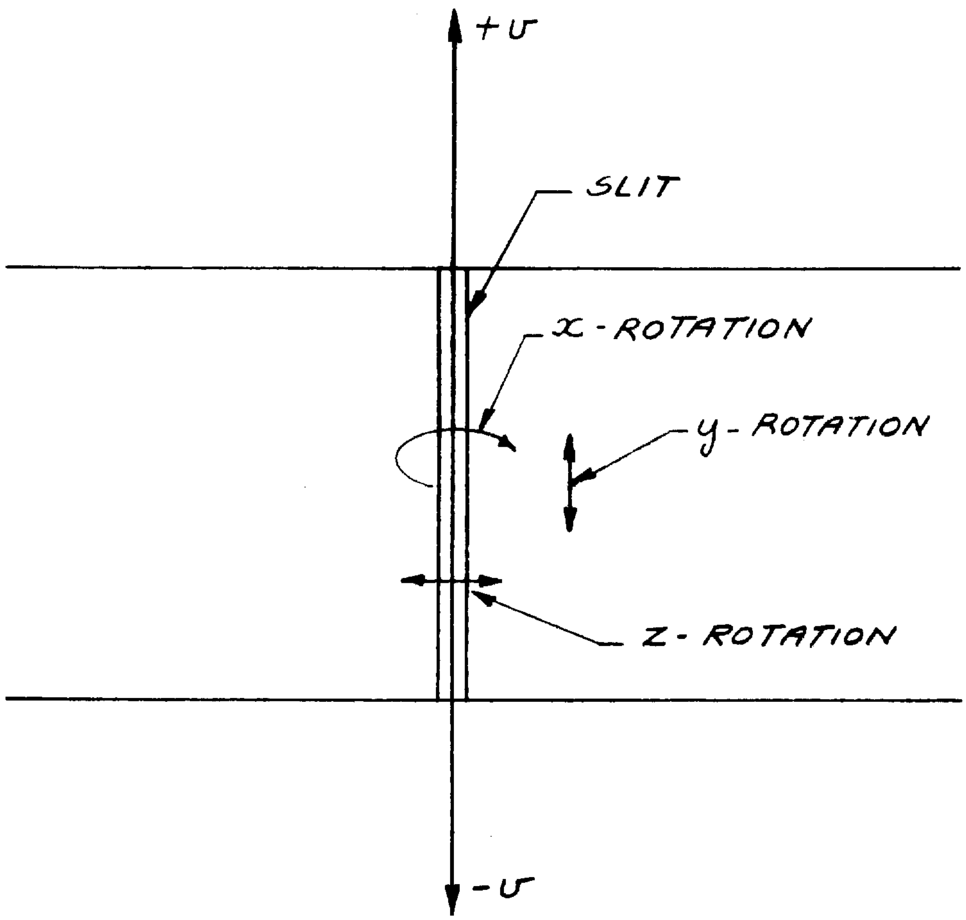

FIG. 5

951L34

SECRET

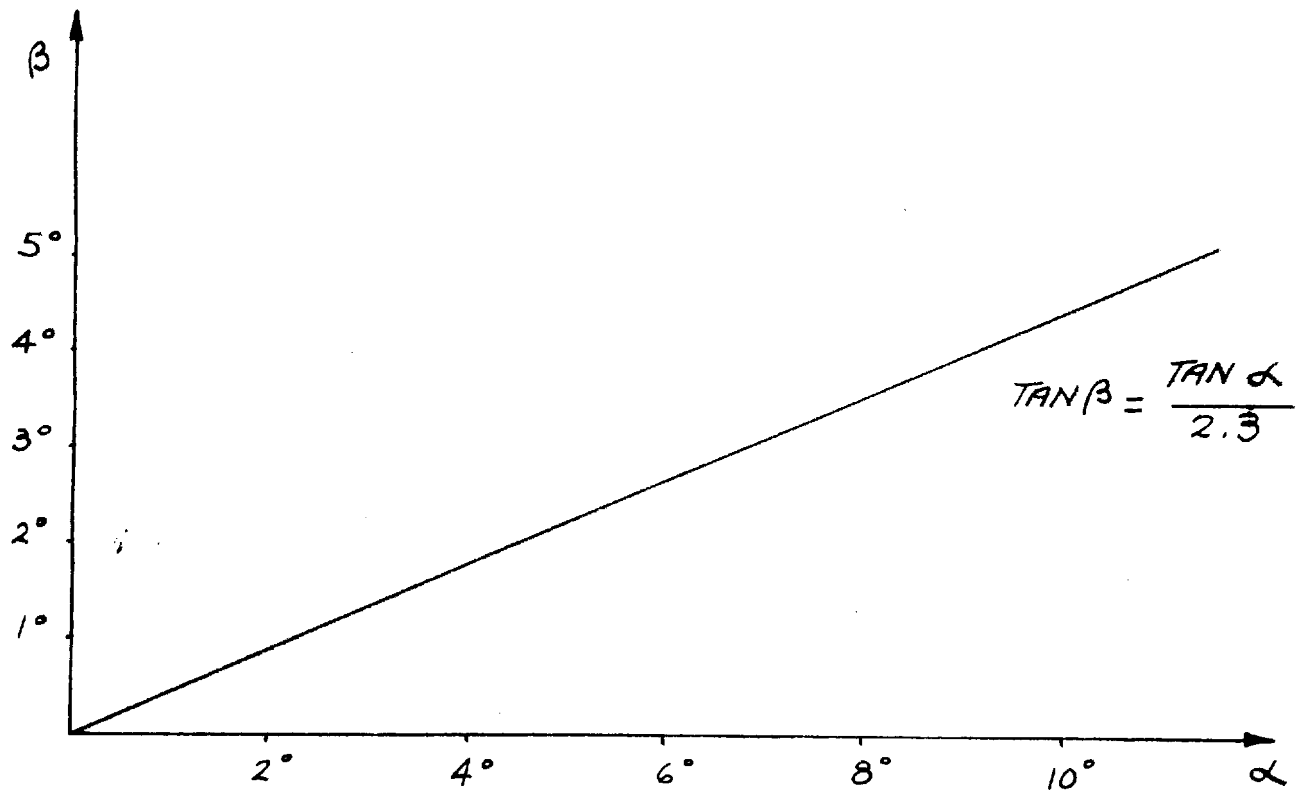

FIG. 6

951 L 35

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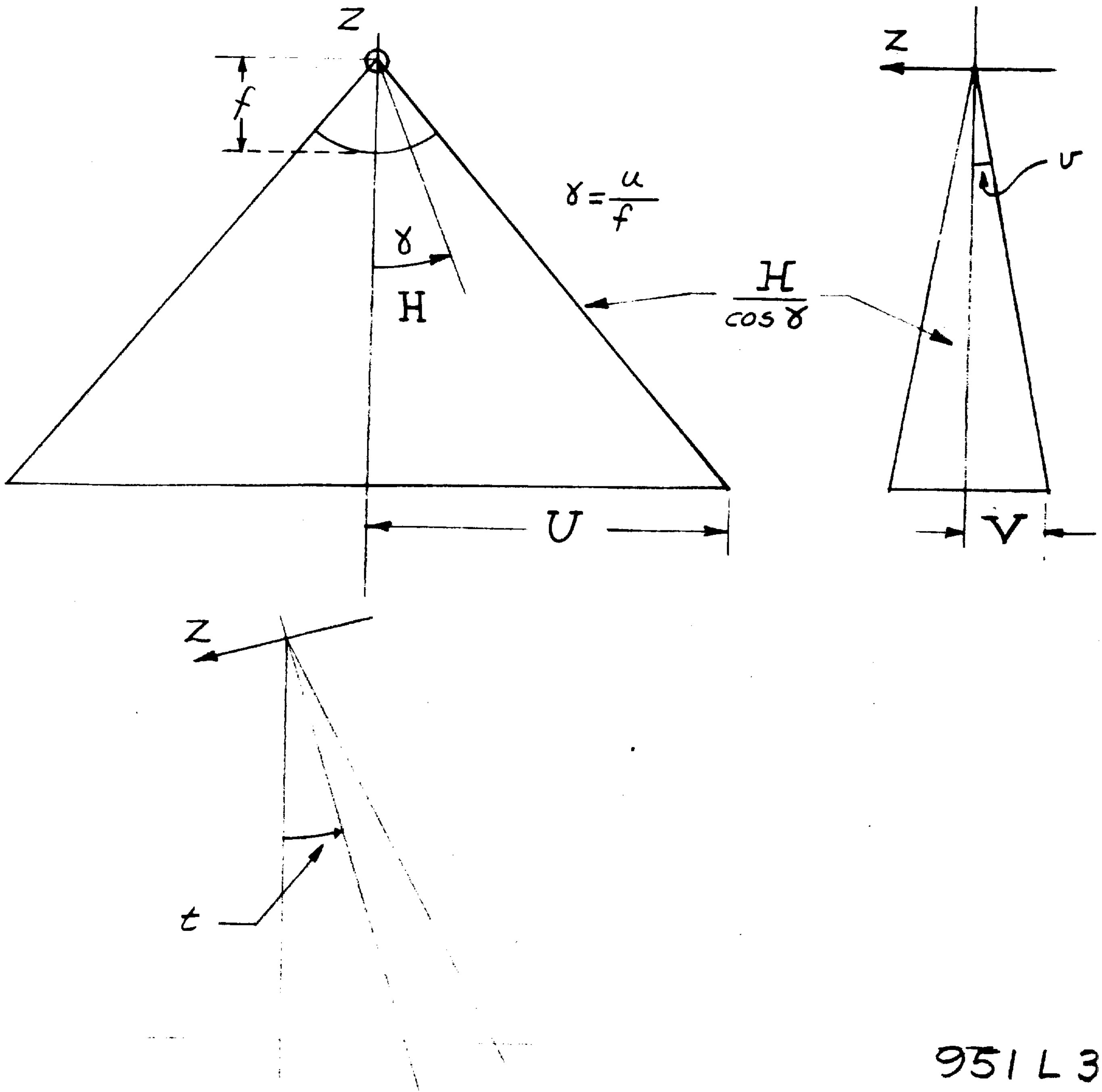

FIG. 7

951 L 36

FAIRCHILD CAMERA AND INSTRUMENT CORPORATION

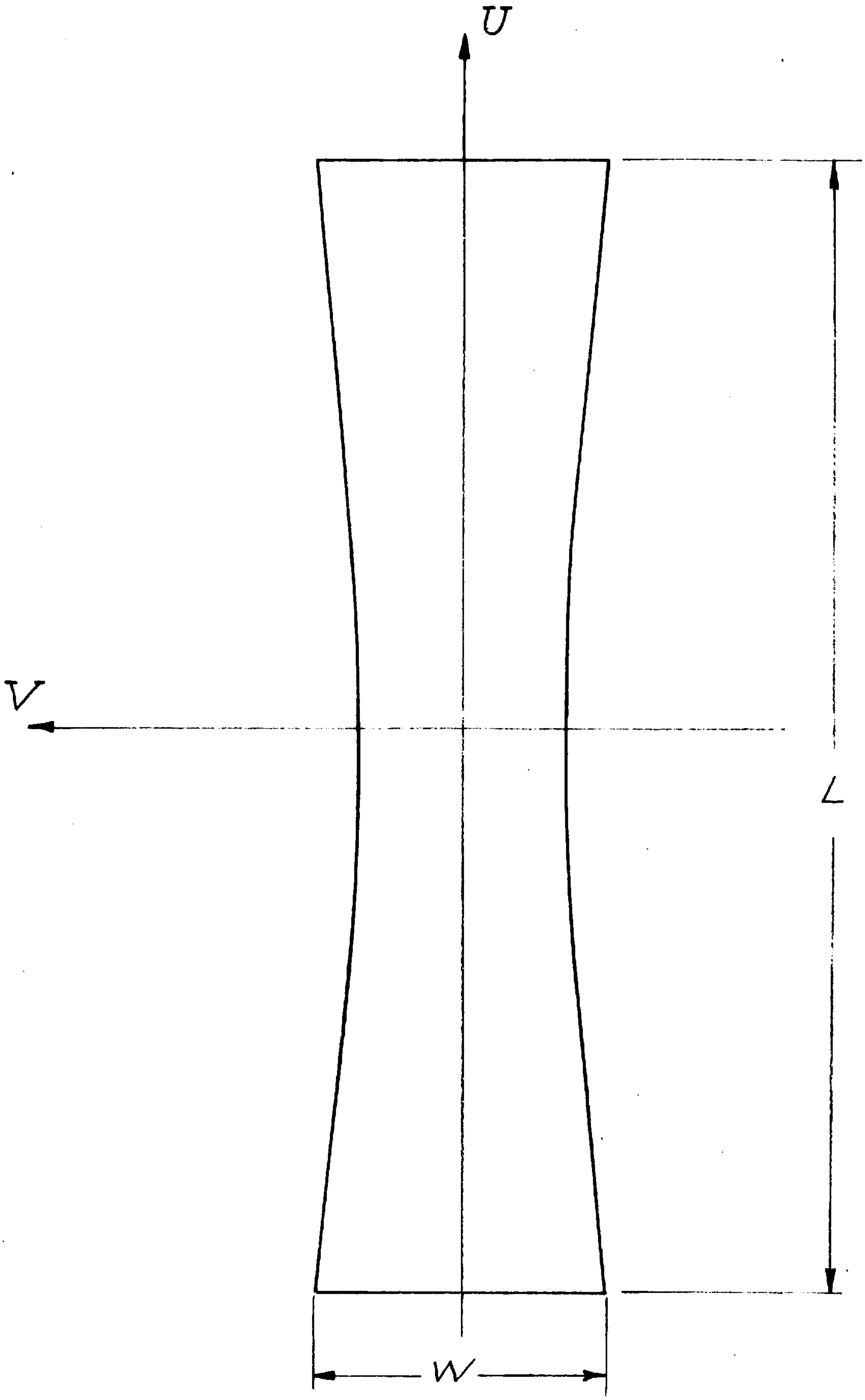

FIG. 8

951L37

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APPENDIX II

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation
5 Aerial Way, Syosset, New York

Report No. SME-AF-1
27 March 1958

EFFECTS ON PHOTOGRAPHIC FILM RESULTING FROM IMMERSION IN SALT WATER AND SALT WATER PLUS YELLOW DYE MARKER

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SECTION I

INTRODUCTION

The purpose of this investigation was to determine the sensitometric and physical effects on Type IB Class L film resulting from immersion in sea water and in sea water plus yellow dye marker for up to 72 hours.

In general, after immersion, film contrast, maximum density, and density scale increased, base plus fog density remained unchanged, and film speed decreased. No physical damage was apparent except when wetted film was allowed to dry or the film was only partially wetted (so as to be tacky). No effect was noted on sensitometric characteristics as a result of an 11,000 g shock.

It was recommended that extreme care be taken to keep the film either completely wet or completely dry. If wetting cannot be avoided, complete data should be obtained on loss of film speed (which from these tests appears to be 1/2 to 1 stop) and on revised processing procedures required to obtain the desired sensitometric characteristics for the particular film chosen. It would be desirable to determine the effects of sea water immersion on resolution, acuity, and granularity.

SECTION II

PROCEDURE

Four solutions were chosen for these tests; sea water and sea water plus 10 ppm, 100 ppm, and 1,000 ppm yellow dye marker. Type IB Class L film (Super XX- RP) was used in all tests.

A total of 24 test conditions as tabulated in Table 1 were investigated. Use of a 700 ft. roll for each condition would be prohibitively expensive. Therefore, initial efforts were directed towards obtaining a correlation between results of immersion of a complete 700 foot roll of 5 inch perforated film and immersion of standard sensitometric film strips (9-3/4 inches x 35 mm).

After each test procedure was completed, the sensitometric strips were developed for 5 minutes in Eastman Kodak D-19 at 70°F, and stopped, fixed, washed, and dried in the conventional manner. Strip densities were then read and H & D curves constructed. A detailed description of the test procedure can be found in the Appendix.

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TABLE I

TEST CONDITION	SEA WATER	SEA WATER PLUS YELLOW DYE MARKER IN CONCENTRATION OF: 10ppm	100ppm	200ppm	1,000ppm
1. Soak for 48 hrs., let dry, set for 48 hrs. and process	Strips*	Strips	Strips	-	Strips
2. Soak for 70 hrs., then rinse in running fresh water for:					
a. 5 minutes	Strip	Strip	Strip	-	Strip
b. 10 minutes	Strip	Strip	Strip	-	Strip
c. 15 minutes	Strip	Strip	Strip	-	Strip
d. 20 minutes	Strip	Strip	Strip	-	Strip
3. Soak for 72 hrs., 24 hrs. fresh water soak while on spool, then process. Film subjected to 11,000 g's shock for about 40-80 10^6 sec. prior to immersion.	Strip-700 ft. roll	Strip	Strip	Strip-700 ft. roll	Strip

*"Strip" refers to 9-3/4 inch by 35 mm Sensitometric Strip.

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SECTION III

RESULTS

Sensitometric results are shown in Figures 1,2,3,4,5,6, and 7. Figures 1,2,3, and 4 are H&D curves showing results of film immersion in sea water and sea water plus yellow dye marker followed by a running fresh water wash for several different times. Figures 5,6, and 7 are plots of fog level, eleventh step (on sensitometric step tablet) and maximum density for various dye concentrations versus time of fresh water wash after immersion and before processing.

A. Specific Observations (Refer to Table I)

1. Test Condition 1, Table I

The film samples were dried after sea water-dye marker immersion and before processing.

a. All seven film strips were highly fogged and had highly varigated densities. Only one strip was readable.

2. Test Condition 2, Table I

Results are shown in Figures 1 through 7. The H&D curves show that the strips wound in a tight coil had a lower fog and maximum density than strips completely exposed to the solution. Apparent film speeds of both coiled and uncoiled strips were lower than the control strip, with the coiled strips having higher speeds than the uncoiled strips in all but one test.

The length of rinse time after sea water and sea water plus dye immersion from 5 to 20 minutes had no measurable effect on sensitometric results.

3. Test Condition 3, Table I (strips)

Results are shown in Figure 1. From Figure 1 it can be seen that a strip immersed in sea water gives sensitometric results that are extremely similar to the wedge exposure on the 700 ft. roll. On this basis, it is proposed that the coiled strips be used as a reasonable measure of the effect of sea water on the spooled film.

4. Test Condition 3, Table I, Fresh Sea Water with 700 ft. roll of Film.

a. The sea water was colorless at start of test, after film immersion the water became amber color and had an orange-yellow suspension of small particles. This indicates serious leaching of the emulsion or anti-halation back coating.

b. The inboard wedge (close to spool core) was clean.

c. The wedge in the center of the roll was clean.

d. The outboard wedge (close to outside wrap of spool) was clean. Figure 1 is an H&D plot of the wedges obtained from this test along with a control wedge plot.

5. Test Condition 3, Table I, Sea Water plus 200 ppm Dye Marker

a. The first fifty feet or so of the 700 ft. roll was stained by dye-sea water solution. The remaining film was wetted only at the perforations. The inboard, or core end, was affected in the same manner.

b. The major damage consisted of emulsion sticking to the film base resting against it. Sticking was confined primarily to the perforation area.

c. After film immersion the water became more deeply colored (green-yellow) with a smaller concentration of the orange-yellow particles observed with pure sea water.

d. The outboard wedge (close to the outside wrap on the spool) was badly damaged by pinholes.

e. The inboard wedge (close to the spool core) was damaged by pinholes, but not as severly as the outboard wedge.

f. The wedge in the center of the roll was undamaged.

g. No pressure marks resulting from 11,000 g impact were evident.

SECTION IV

DISCUSSION OF RESULTS

A. Sensitometric Characteristics

The increase in maximum density, density scale, and contrast and the decrease in apparent film speed shown in Figures 1-4 are not explained. This trend held through all tests where film was immersed in sea water or sea water plus dye marker.

Two important inferences can be drawn from these facts. First, the apparent speed loss of from 1/2 to 1 stop will have to be compensated for during exposure. Higher contrast is normally associated with longer developing times (up to a limit of course). Also, with longer developing times, apparent speed also increases. Since the strips immersed in sea water showed a higher contrast and maximum density and a lower apparent speed, an analogy between sea water immersion and enhancement of developer action, or pre-developing is highly unlikely. The second important consideration is the slightly higher contrast and much higher maximum density, concomitant with a very small increase in base plus fog density. If highly accurate contrast and density scale control is important during film processing, film developing times must be modified, a shorter time being required to obtain the same density scale and contrast for film immersed in sea water. It should be noted that a decrease in developing time will contribute an additional loss in apparent film speed.

As indicated in Figures 5, 6, and 7 the length of fresh water rinse from 5 to 20 minutes after immersion in sea water and before processing, had no measurable effect on sensitometric characteristics.

B. Physical Characteristics

The only serious damage to test samples resulted when the film, once wetted in sea-water, was allowed to dry. When complete rolls were allowed to partially dry or were not completely wetted, film emulsion adhered very strongly to the film base resting against it. Individual strips allowed to dry before processing were extremely mottled, the resulting sensitometric step densities being completely unreadable. This was possibly due to bacterial action on the emulsion.

SECTION V

RECOMMENDATIONS

A. Obviously the film should be completely protected from contact with sea water.

B. If it is impractical, the film, once wetted, should be maintained completely soaked until processed. After recovery, storage in fresh water is preferred to sea water.

C. Future Work

1. If sea water immersion cannot be avoided, more detailed data will have to be obtained on the exact loss of speed resulting from immersion for the specific film to be used and on the modification to processing times that will be required to obtain the desired sensitometric characteristics.

2. If time and resources are available, it would be desirable to determine effects on image "quality" resulting from sea water immersion. By "quality" it is meant as indicated by measurements of resolution, acuity, granularity, etc.

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SECTION VI

APPENDIX

A. Detailed Procedure

1. Tests With Complete Rolls of Film

Materials and Equipment

a. Argon Contact Printer
Exposure 1/25 sec. (filtered by two sheets vellum)

b. D-19 Developer 68°F, 5 min.

c. Two five gallon buckets.

d. Ten gallon fresh salt water.

e. Conc. Dye Marker.

f. 5-1/2 inch film rewind.

g. Super XX IBL, 5-1/2" x 700 ft. spooled.

Method

The film was supplied immediately after the 11,000 g drop test and was rewound on spools. The salt water was obtained fresh from Long Island Sound. Four gallons were put into each bucket; one bucket contained only salt water and to the other bucket was added 3g of dye marker, 3g/4 gal. Three step wedges printed on the argon contact printer using an uncalibrated Kodak step wedge were printed on each 5-1/2" x 700 ft. spool of Super XX film, extreme ends and middle. On 2-15-58 at 1600 hours one spool of film was placed in one bucket containing fresh salt water. The other spool was placed in another bucket containing fresh salt water plus 3g/4 gal. dye marker. The buckets were sealed to prevent light fogging the film.

On 2-18-58, three days later, the exposed wedge portions of the film were cut from the spool and marked accordingly. These wedges were processed in EK D-19 developer for five minutes at 68°F, read on the Eastman Kodak densitometer and plotted along with a control step wedge.

2. Tests With Sensitometric Strips

Materials and Equipment

a. Herrnfeld 1B Printer 2.5 ND + #5900 (day) filter.

b. Super XX 1BL strips, 9-3/4 x 35 mm

c. E.K. D-19 Developer for 5 minutes at 70°F.

d. Four-one liter beakers.

e. Fresh salt water, from Long Island Sound.

f. Dye Marker.

Method

Four-one liter beakers were filled with fresh salt water. To three of the beakers was added 10ppm, 100ppm, and 1,000 ppm of dye marker respectively. Dye marker was not added to the fourth beaker. These beakers were marked accordingly and placed in a large can with a light tight lid.

Strips of Super XX 1BL film were exposed on the Herrnfeld 1B Sensitometer. Four exposed strips were wound tightly into a coil with an extra strip for the inside core and bound by a rubber band. One set of strips bound thusly was immersed in each one of the four beakers. Four loose single strips were also immersed into each one of the four beakers. The lid was placed on the can and taped to eliminate any stray light and set aside gently for 72 hours. At the end of the prescribed time the strips were rinsed for 5, 10, 15, 20 minutes processed and dried. Processing was accomplished by taping exposed film strips to plate glass and placing in a tray of developer. The agitation was provided by constantly rocking each edge of the tray in succession. The densities were then read and curves plotted for the five minute rinse. A graph was plotted showing maximum and minimum density versus time in running water rinse.

OUTLINE OF PROCEDURE:

1. Soak Strips for 48 hrs.	- sea water -	let dry and set for 48 hrs. and process.
"	sea water +10ppm dye	"
"	sea water +100ppm dye	"
"	sea water +1000ppm dye	"

Two Conditions (a) wound tight
(b) loose strips

Time Started 1600 2-21-58

Finished 1100 2-24-58

Time 67 hours

2. Soak Strips for 48 hrs. - sea water plus 10ppm dye (0.1g/ℓ)

Finished 1380 2-24-58
Time 69 hours

5 minute running water rinse
10 "
15 "
20 "

3. Soak Strips for 48 hrs. - sea water plus 100 ppm dye (.1g/ℓ)

Finished 1420 2-24-58
Time 70 hours

5 minute running water rinse
10 "
15 "
20 "

4. Soak Strips for 48 hrs. - sea water plus 1000ppm dye (1.0g/ℓ)

Finished 1515 2-24-58
Time 71 hours

5 minute running water rinse
10 "
15 "
20 "

3. Control Strips

Five control strips were exposed and processed in the same manner as the test (no sea water immersion). The density readings of all five strips were found to be identical for all practical purposes.

Test 1 - The two conditions of exposed strips were removed from the solutions of salt water and dye marker and hung up to dry in a light tight container for 48 hours, then processed in D-19 for 5 minutes at 70°F. Seven strips were highly fogged and with varigated densities. Only one strip was readable. It is possible that the first strips taken off each coil was effected by the salt water and dye solutions, and not being processed until after 48 hours in a dry state they were affected by chemical and bacterial action of the salt water and dye solutions.

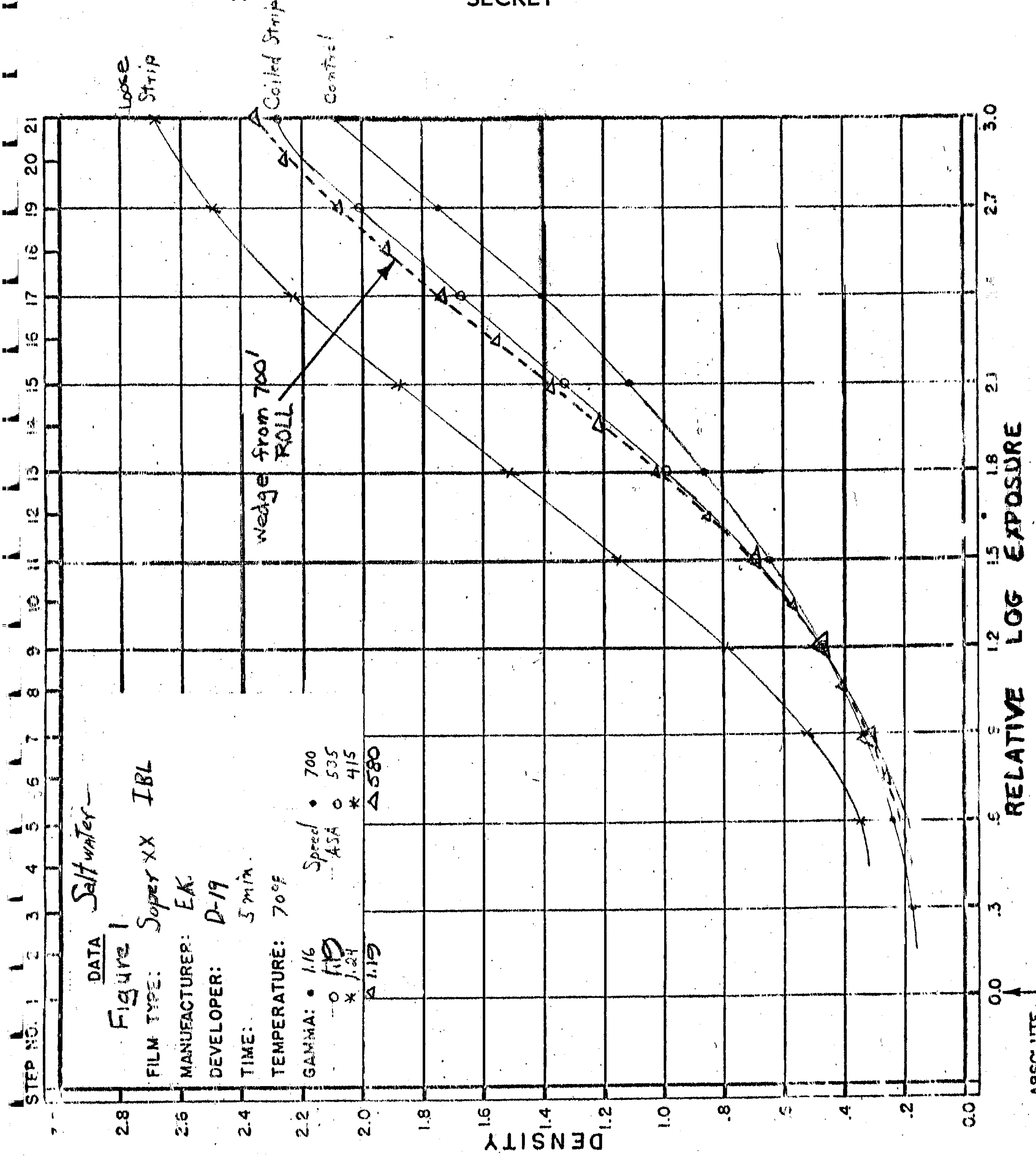
These strips were not read and plotted.

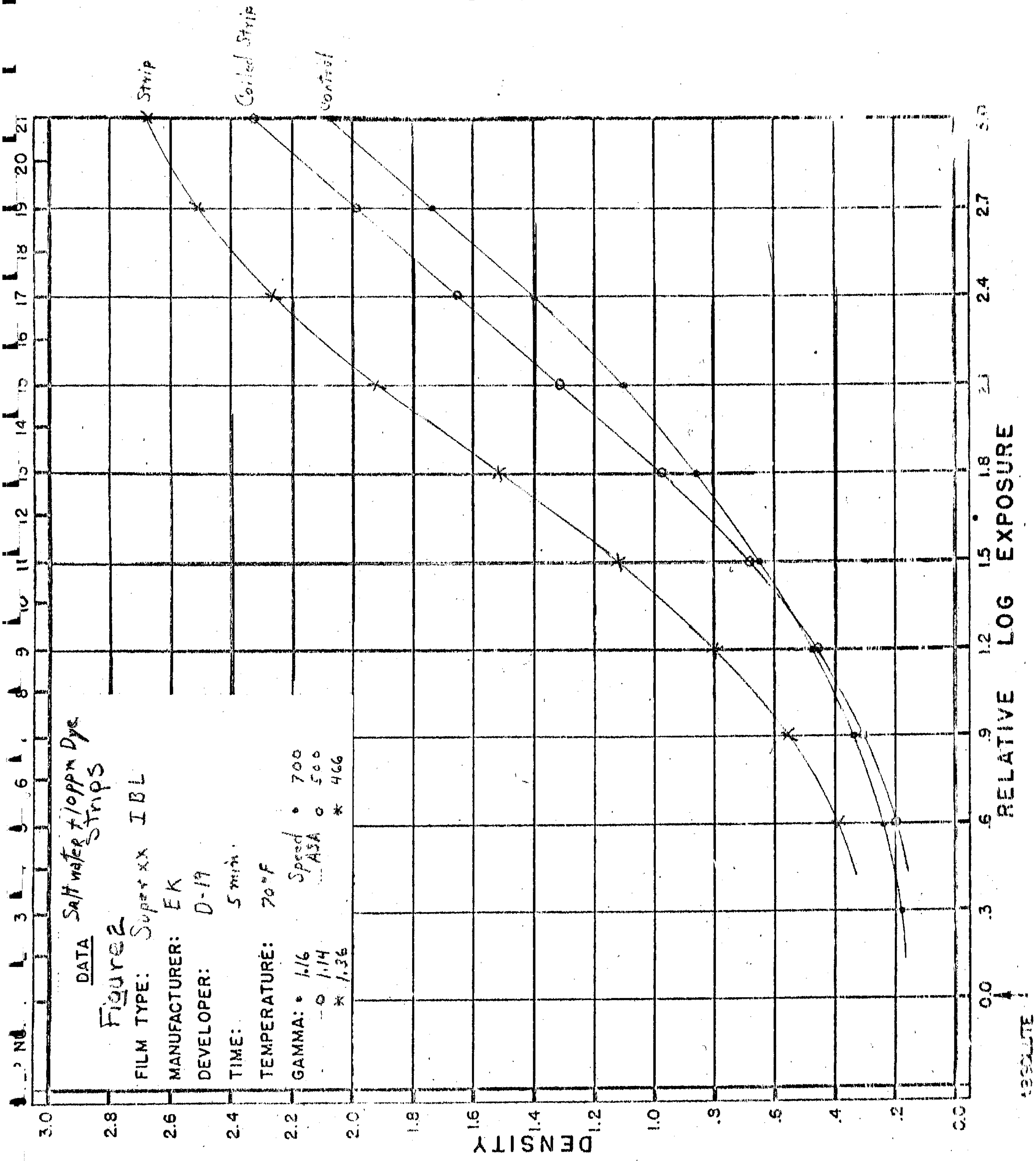
Test 2 - The two conditions of exposed strips were removed from the solution of salt water and 10 ppm dye marker, placed in a tray of running water for 5, 10, 15 and 20 minutes and then processed in D-19 for 5 minutes at 70°F. The densities of each strip were read.

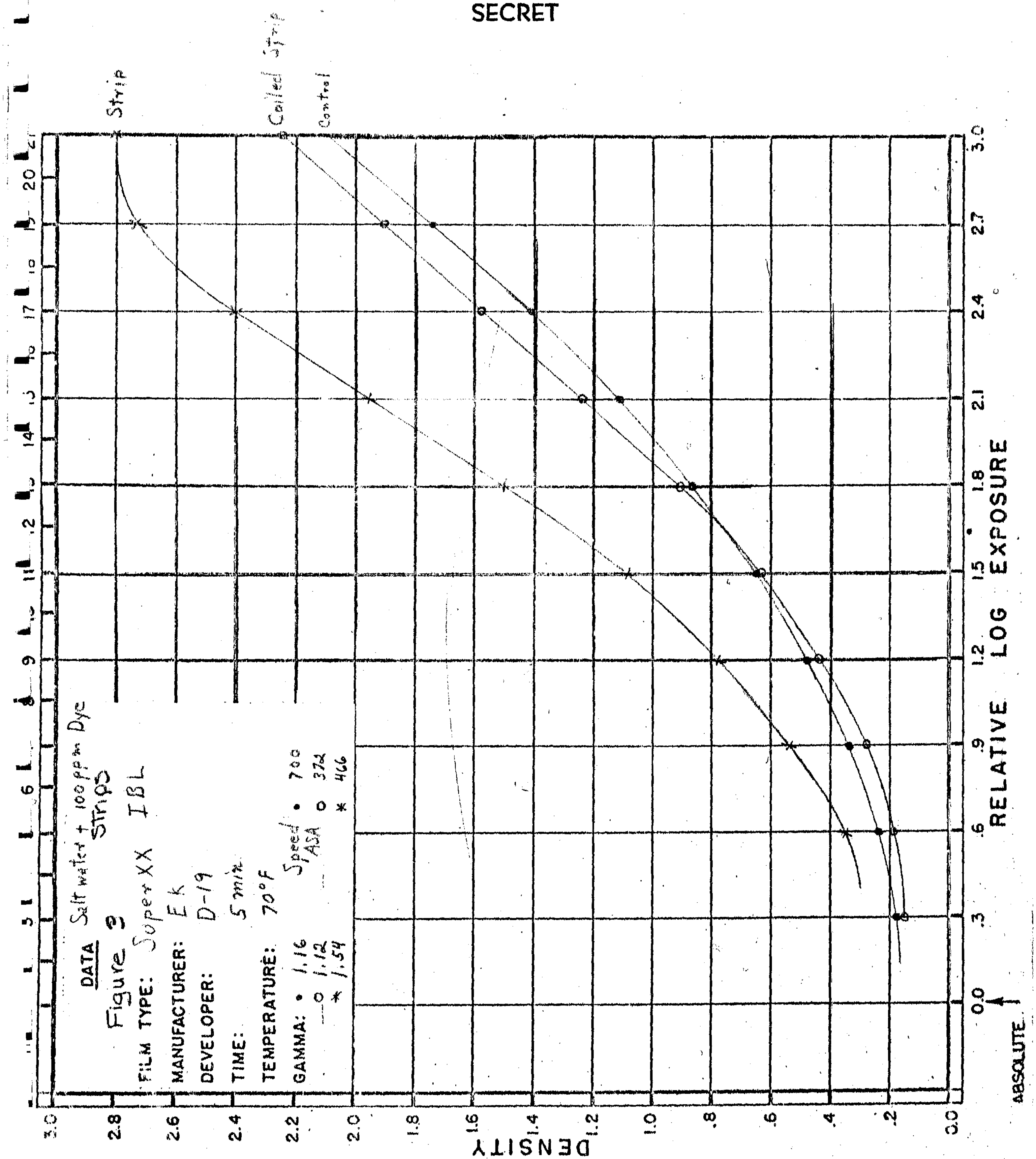
The strips that were wound tight, emulsion to back, had a lower fog and maximum density than strips that were loose. There was no indicated difference in the 5 minutes rinse through the 20 minute rinse.

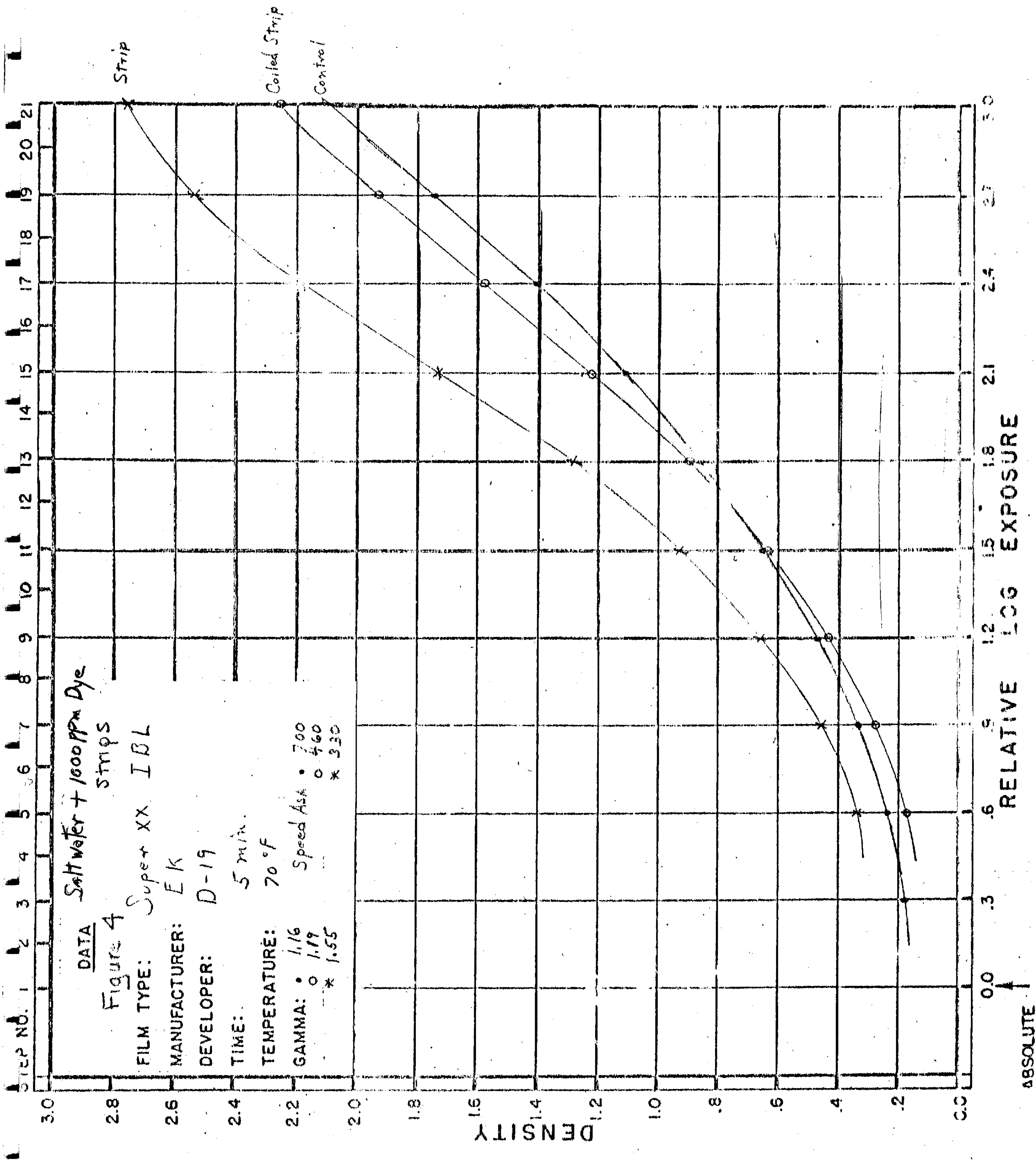
Test 3 - The two conditions of exposed strips were removed from the solution of salt water and 100 ppm dye marker, placed in a tray of running water for 5, 10, 15, and 20 minutes and then processed in D-19 for 5 minutes at 70°F. The resulting densities indicate that the strips wound tightly in a coil had a lower fog and maximum density than the strips that were totally exposed to the solution. There is no real difference in the running water rinse, 5 minutes through 20 minutes.

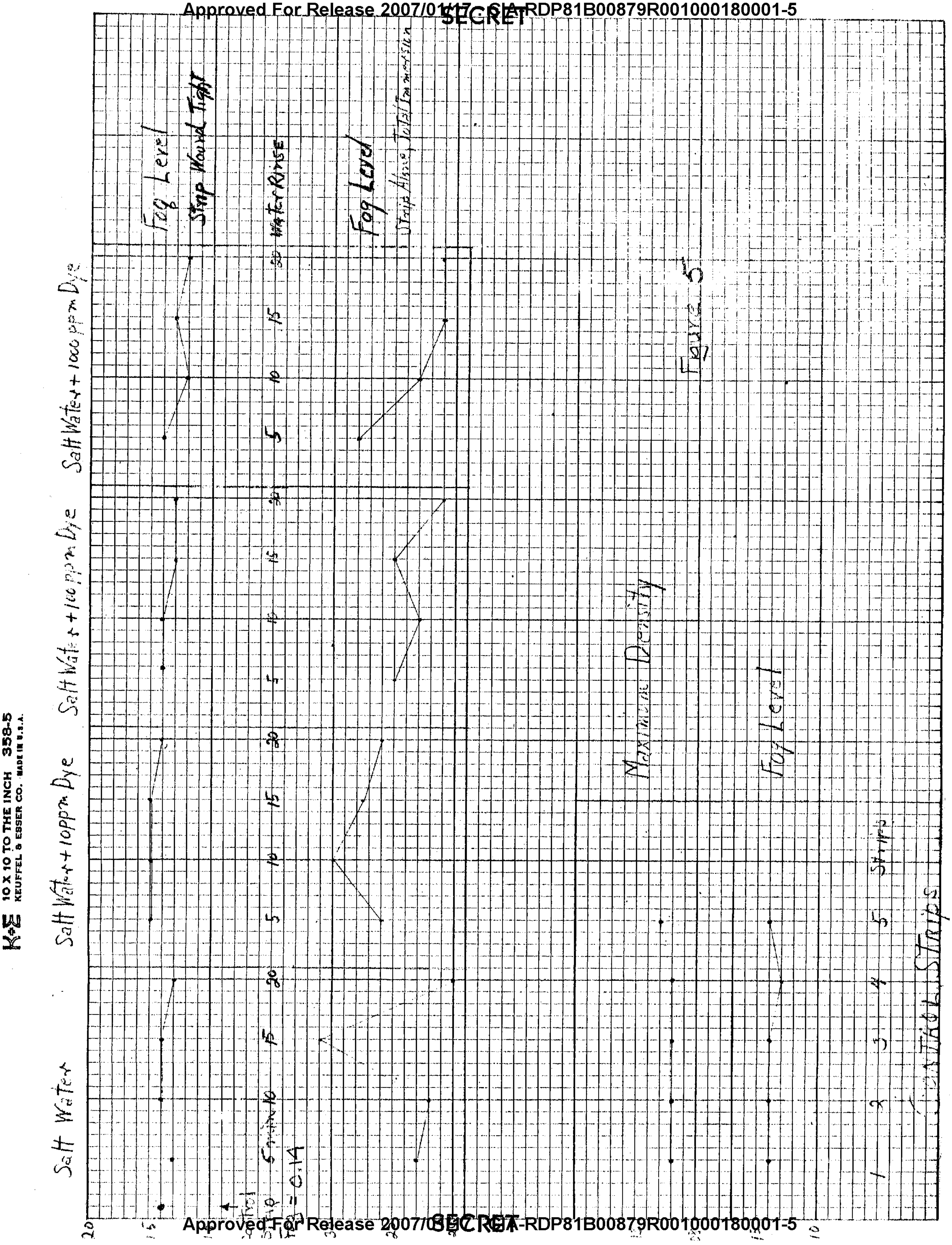
Test 4 - The two conditions of exposed strips were removed from the solution of salt water and 1000 ppm dye marker, placed in a tray of running water for 5, 10, 15, and 20 minutes and then processed in D-19 for 5 minutes at 70°F. The resulting densities indicate that the strips wound tightly in a coil had lower fog and maximum densities than the strips that were totally exposed to the solution. The density differences from the running water rinse 5 minutes through 20 minutes is neglegible.

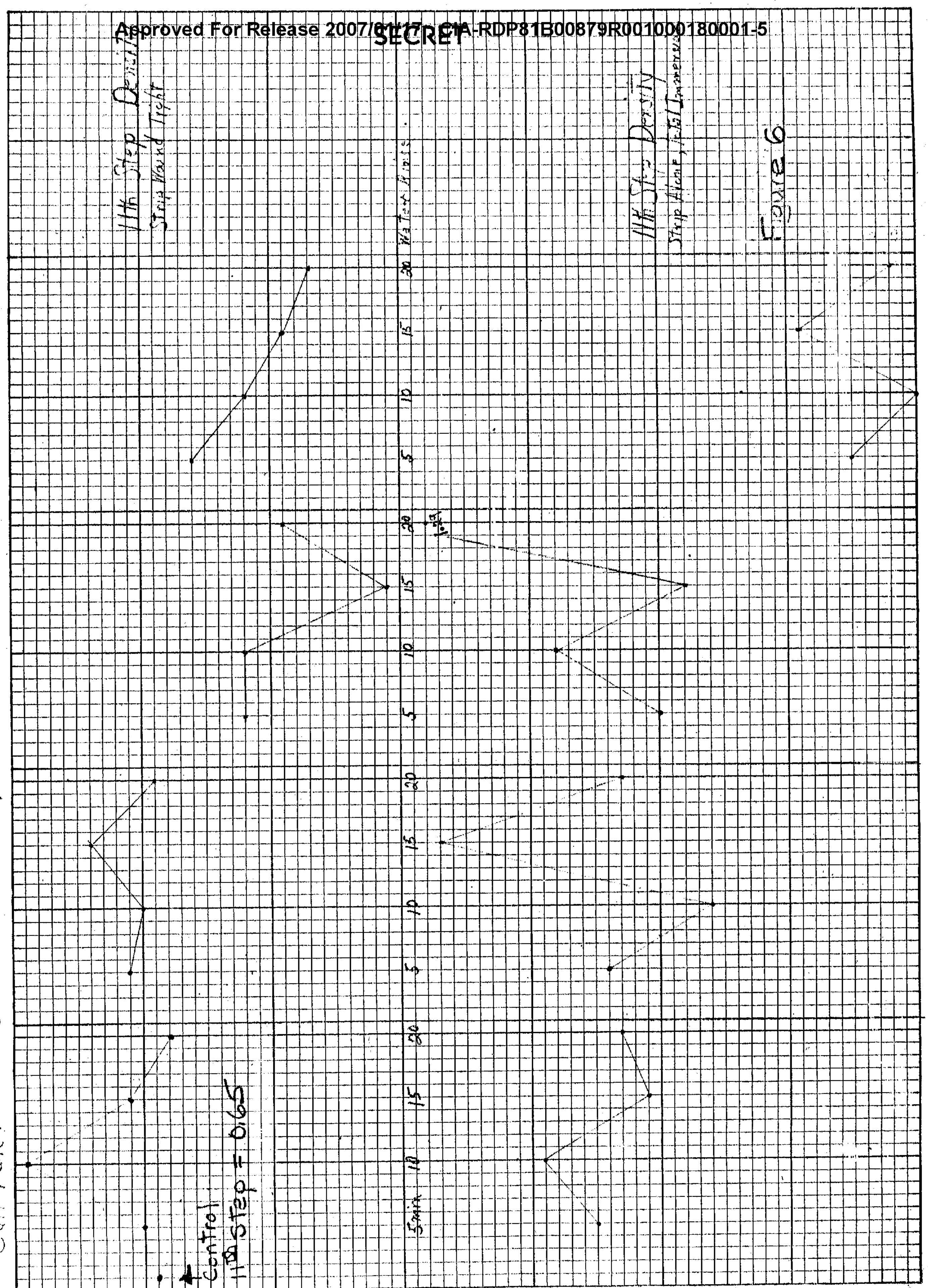

DATA
Figure 1
Saltwater
FILM TYPE: Super XX IBL
MANUFACTURER: EK
DEVELOPER: D-19
TIME: 5 min
TEMPERATURE: 70°F
GAMMA: • 1.16 o 1.10 * 1.24 Δ 1.19
Speed ASA • 700 o 535 * 415 Δ 580
Loose Strip
Coiled Strip
Control
Wedge from 700' ROLL
STEP NO.
DENSITY
RELATIVE LOG EXPOSURE

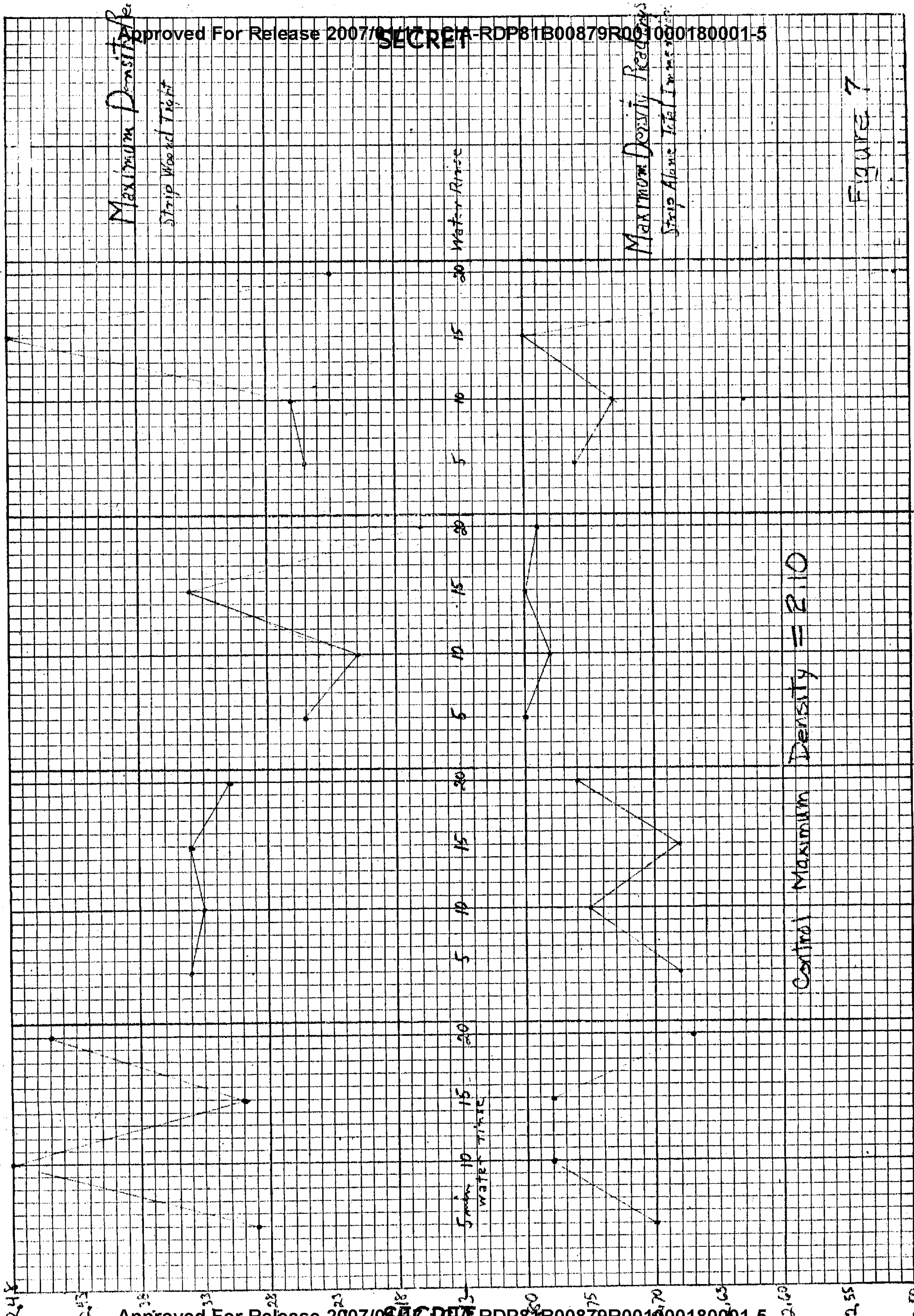

Strip
Coated Strip
Control
DATA
Figure 2
Salt water + 10ppm Dye Strips
FILM TYPE: Super XX
MANUFACTURER: EK
DEVELOPER: D-19
TIME: 5 min.
TEMPERATURE: 70°F
GAMMA: • 1.16
o 1.14
* 1.36
Speed ASA • 700
o 500
* 466
IBL
DENSITY
RELATIVE LOG EXPOSURE


DATA
Figure 9
Salt water + 100 ppm Dye Strips
FILM TYPE: Super XX IBL
MANUFACTURER: Ek
DEVELOPER: D-19
TIME: 5 min
TEMPERATURE: 70°F
GAMMA: • 1.16 o 1.12 * 1.54
Speed ASA • 700 o 372 * 466
Strip
Coiled Strip
Control
RELATIVE LOG EXPOSURE
DENSITY
ABSOLUTE


Strip
Coiled Strip
Control
DATA
Figure 4
Saltwater + 1000ppm Dye
strips
FILM TYPE: Super XX IBL
MANUFACTURER: EK
DEVELOPER: D-19
TIME: 5 min.
TEMPERATURE: 70 °F
GAMMA: • 1.16 o 1.19 * 1.55
Speed Ask • 700 o 460 * 330
STEP NO.
RELATIVE LOG EXPOSURE
ABSOLUTE
DENSITY


K+E 10 X 10 TO THE INCH 358-5
KEUFFEL & ESSER CO. MADE IN U.S.A.
Salt Water
Salt Water + 10ppm Dye
Salt Water + 100 ppm Dye
Salt Water + 1000 ppm Dye
Fog Level
Strip Wound Tight
Water Rinse
Fog Level
Maximum Density
Fog Level
Figure 5
Strips
Control Strips


Salt Water
Salt Water + 10ppm Dye
Salt Water + 100ppm Dye
Salt Water + 1000ppm Dye
11th Step Density
Strip Washed Tight
11th Step Density
Figure 6
Control
11th step = 0.65


Maximum Density Readings
Strip Alone
Figure 7
Water Rinse
Salt Water + 1000 ppm Dye
Salt Water + 100ppm Dye
Salt Water + 10ppm Dye
Salt Water
Control Maximum Density = 2.10
5 min water rinse
5
10
15
20

25X1

SECRET
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